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Green energy transformation in Poland

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Abstract. Is the world's power engineering at a crossroads? Will ongoing climate changes and rise of new technologies such as the Internet of Things (IoT), Smart City or e-mobility give us a completely different perspective on the world's future energy? What are our actual visions and development forecasts in this matter? Who is right concerning this matter, large energy companies and some politicians, environmentalists, climate researchers and all kinds of visionaries? Is transformation based on solar energy and hydrogen a holy grail for the energy sector? The author of this article tries to find answers to these and many other questions. Today we can already accept as a proven thesis that rapid and dangerous climate changes for our civilisation can also be attributed to high carbon and low-efficient power engineering. Power engineering and climate neutrality are no longer just problems for politicians, companies, and scientists, but have become a challenge for our civilisation. If we are to save the Earth, our civilisation has to change its mentality and develop ideas that will not prioritise economic growth and high consumption but sustainable growth in harmony with nature. For this to happen, the way people think about energy and global transformation must also change. The foregoing general remarks, but also the fact that a gradual transition from traditional large-scale fossil fuel-based energy generation to distributed energy generation based on renewable resources is inevitable, constitute the main message of this article. The article also aims to discuss the role of the Institute of Fluid-Flow Machinery of the Polish Academy of Sciences (IMP PAN) in Gdańsk in the process of energy transformation in our country. The institute, as the coordinating entity of over a dozen of high-budgeted national and European projects in the field of environmentally-friendly power engineering, has contributed to some extent to the creation of conditions required for the development of prosumer power engineering (or more broadly: civic power engineering) in our country.

Key words: environmentally friendly power engineering; energy transformation; low-emission technologies; civic power engineering.

1. Introduction

When taking a closer look at a process such as energy transformation, we need to stop for a moment and analyse several important issues such as climate change and emissions, Internet development (Smart City, Industry 4.0, intelligent management) and electromobility. The broadly understood *energy* — i.e. traditional power engineering, transportation, and heat engineering — is closely linked to these issues.

Considering aspects such as the "population boom", low energy efficiency, limited reserves of fossil fuels, greenhouse gas emissions, climate changes and the unlimited energy resources of the Sun, global power engineering and many other areas of human activity are faced with an urgent need to reassess their existing traditional development paths and redefine their priorities. The only alternative in my view is a large-scale crisis. Pessimists say: Don't ask whether a crisis is going to happen, ask when it will happen. But it does not have to be that way.

Global reserves of fossil fuels are limited. If we look at these reserves in detail, based on average global forecasts of their use, it turns out that there may only be 50 *years of oil and gas* and around 100 years of coal and uranium left (Fig. 1). This is a dramatically small quantity!

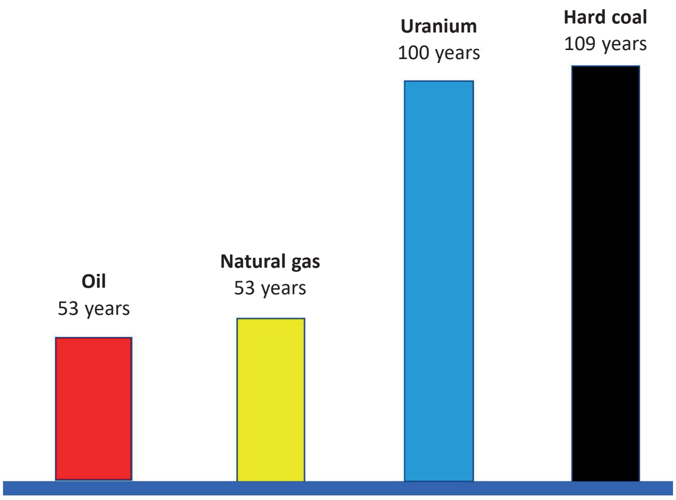

Fig. 1. Average global reserves of fossil fuels

On the other hand, the Sun is an inexhaustible energy source (Fig. 2).

A moment of reflection on Figs. 1 and 2 leads to the conclusion that there is basically one path of transformation: from fossil fuels to solar energy. Only the time needed for this transformation and the transition periods in different regions of the world remain a subject for discussion. Around 45% of solar energy that reaches the Earth can potentially be used directly (e.g. PV cells, collectors) and indirectly — for the production of other environmentally friendly fuels (e.g. hydrogen).

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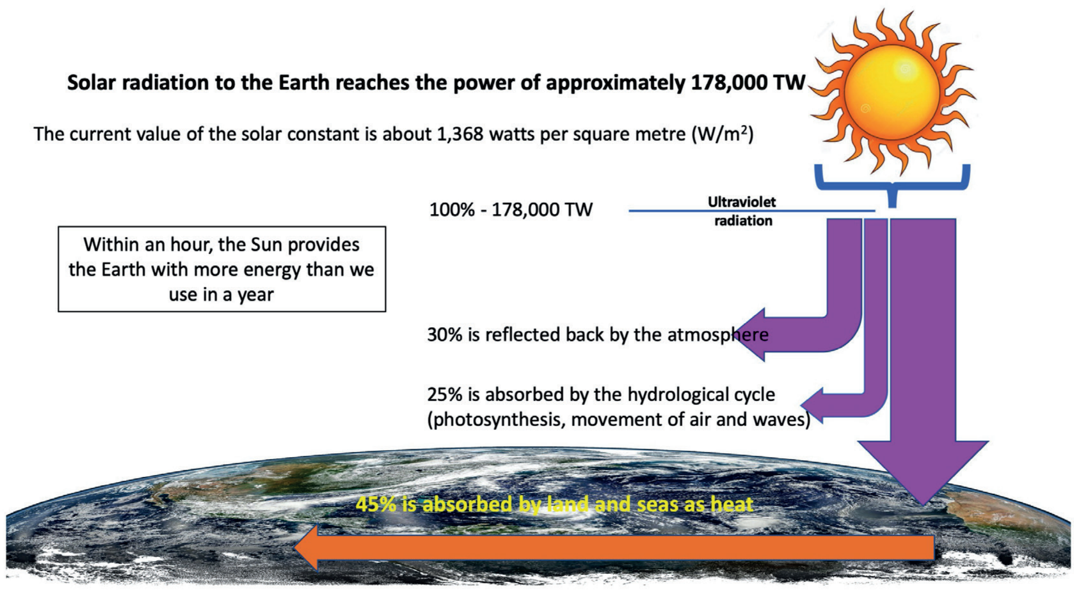


Fig. 2. Energy from the Sun – inexhaustible resources for our civilization

2. Unstable climate balance

Man adds 37 billion tons of CO_2 per year into the natural cycle. Although it is not a large number compared to the total amount of CO_2 and C (pure carbon) circulating in nature, the question is whether nature is able to neutralise this additional rapid increase of CO_2. And hence arises the question about climate balance, which is an unstable balance. This is illustrated in Fig. 3.

The essence of the problem lies in the rapid increase in greenhouse gas emissions in recent decades. Many scientists point to a dramatic and rapid increase in the amount of CO_2 in the Earth's atmosphere.

According to NASA, the concentration of carbon dioxide is rising at an alarming rate. Over the years 2006–2019, it jumped from 380 ppm to 411 ppm. In 1960 it was 318 ppm, and in the pre-industrial era at about 280 ppm. The current CO_2 concentration of about 411 ppm has generated an increase of 1.1°C in the global Earth temperature compared to the pre-industrial era (late 19th century). The current rate of CO_2 growth indicates that we will not have to wait 150 years for the next significant increase in global warming.

While some could agree with the opinion that the growth of CO_2 in the atmosphere (within certain limits) cannot have a major impact on the human body, I think that almost everyone

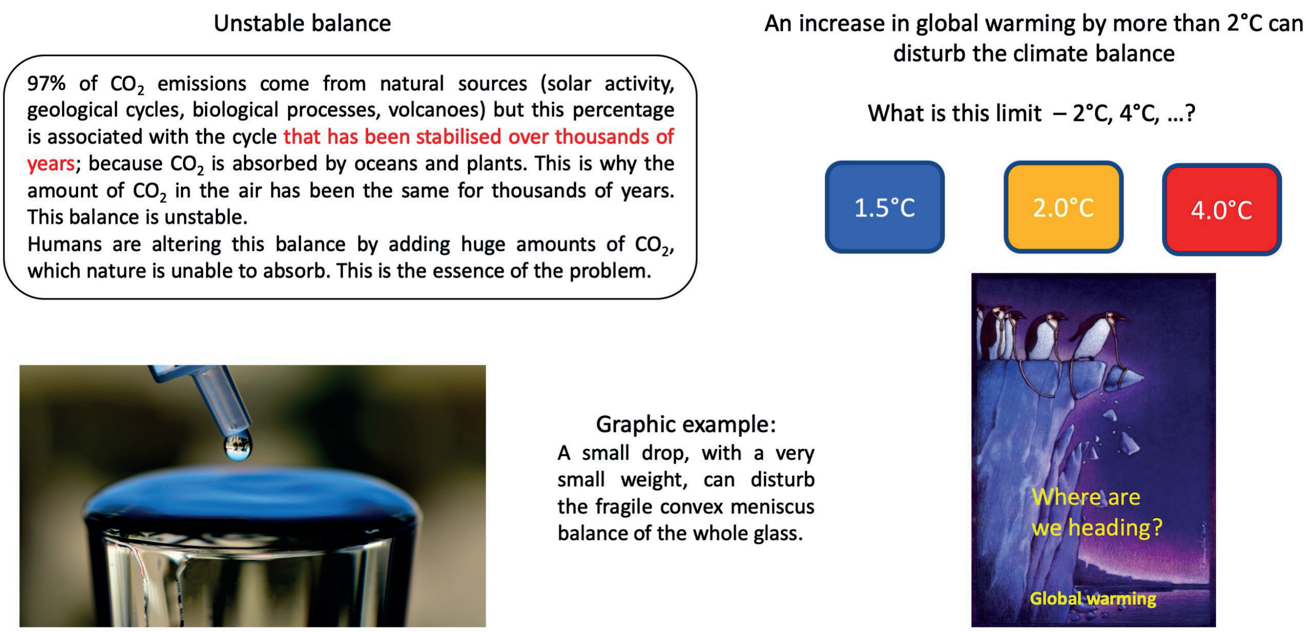


Fig. 3. Unstable climate balance. Where does the limit of global warming lie?

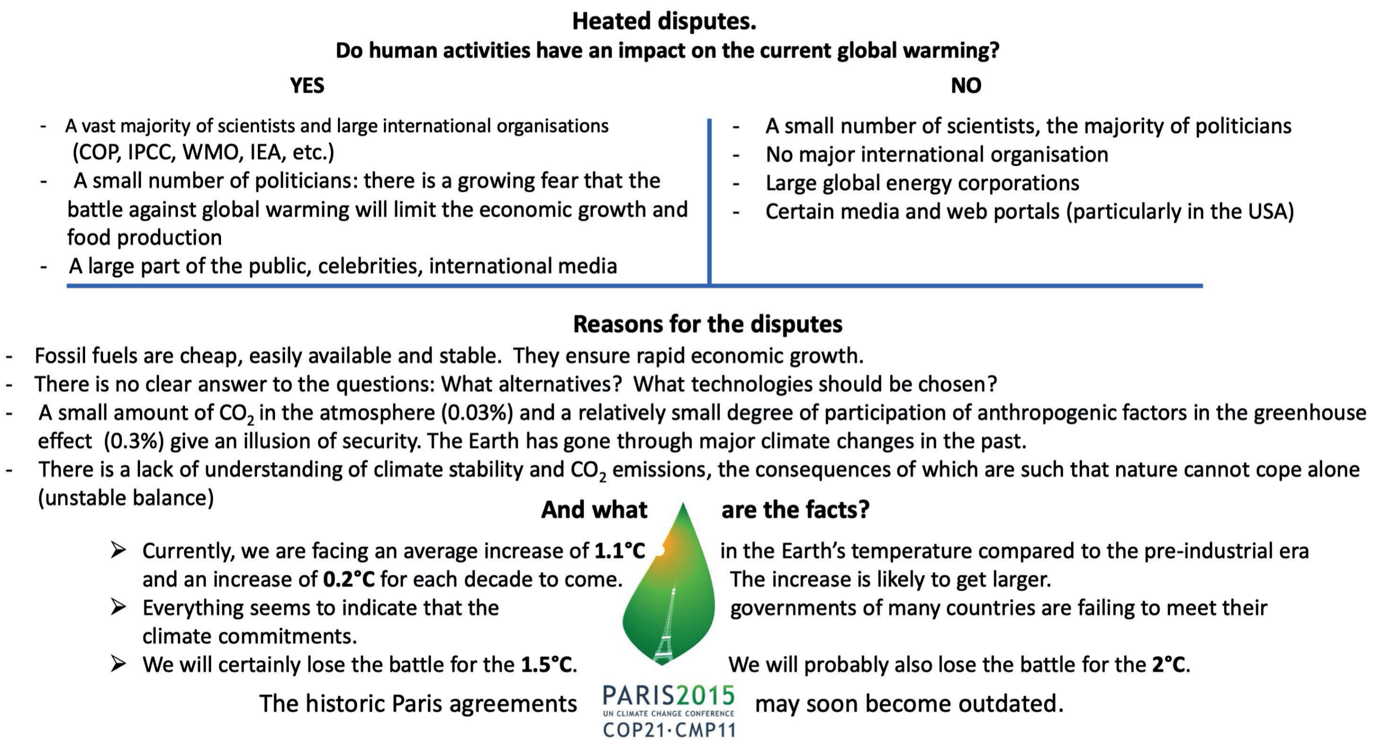


Fig. 4. Does man have an impact on climate changes? A list of arguments – the struggle to limit the global increase in the Earth's temperature below 2°C is likely to be lost

would agree with the statement that the same growth can have catastrophic consequences for global warming and climate (tornadoes, droughts, floods, rise in ocean levels, etc.). An increase of 1°C in the global temperature of the Earth is a lot. And here a legitimate question arises: Will our civilisation cope with such global climate changes [1, 2]?

The truth is that if we are to save the Earth, society must change its mentality and think up ideas that will not prioritise economic development and high consumption but rather an environmentally friendly development in harmony with nature.

This will be an extremely difficult task since economic development and hence high consumption and quality of life have become almost a sort of religion for mankind. Such aspirations are natural, so how can we change the attitude or even mentality of whole generations in this situation?

We are also threatened by a "**climate apartheid**", or another type of climate injustice. The developed countries (mainly: the rich northern countries) are responsible for the majority of greenhouse gas emissions, but it is the inhabitants of the poorest countries (mainly: the poor southern countries) that will suffer the most.

3. European *Green Deal:* new concept

In December 2019, the European Commission announced the *European Green Deal* – an ambitious package of measures that will lead Europe to climate neutrality in 2050 and will enable European citizens and businesses to benefit from a sustainable green transformation. Climate neutrality here means not only stopping the rise in global temperatures and reducing greenhouse gas emissions but also implementing measures such as clean energy (ecological sources), sustainable industry (environmentally friendly production cycles), building and renovation (ecological construction sector), sustainable mobility (eco-friendly transport), biodiversity (ecosystem protection), "from farm to fork" approach (sustainable food chain) and reduction of other pollutants. This is a complex action plan, which aims to improve the quality of human life.

Many politicians, publicists and scientists believe that the *European Green Deal* is the most ambitious project that has been developed to date and an excellent opportunity and challenge of our time. Europe has adopted the *European Green Deal* project, but will other countries of the world follow in its footsteps? There are plenty of indications that they will not. The world's greatest power, the United States of America, declares that it does not have such ambitions (in 30 years, the level of CO_2 emissions will be similar to today's). Other countries (China, India, and Brazil) are of the same opinion. The European Union as a whole currently emits only 10% of the world's CO_2. Carbon dioxide emissions are still growing worldwide and there is no indication that this tendency will change in the near future.

This therefore gives rise to fundamental questions: **Do Europe's climate efforts make sense?** Will the costly green energy transformation find support in other countries of the world? And will Europe not become "*Don Quixote*" in this lonely fight? To answer these questions, it is worth quoting

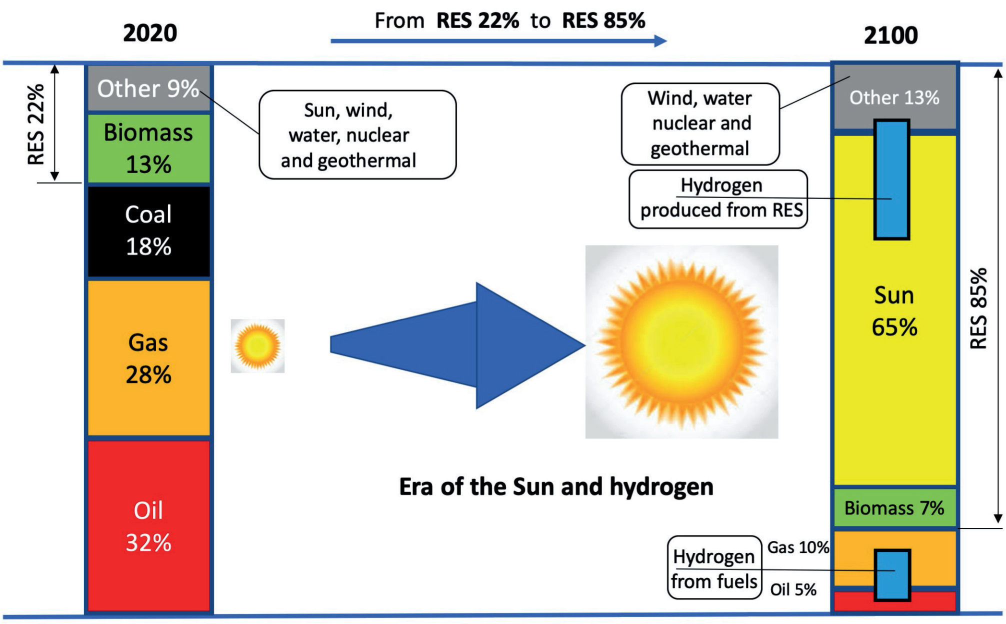


Fig. 5. Forecast of the use of primary energy sources in 2020 and 2100: Will the next century be the solar age for humanity? Will hydrogen be the dominant fuel?

a statement by Jerzy Buzek (who is a member of the European Parliament) at the last European Economic Congress, which was held in Warsaw [3]:

> "*... As Europeans, we must show the world — it is our civilisational obligation — that it is possible to lower the consumption of fossil fuels and that it is possible to keep people employed and Europe will still be the most attractive continent for billions of citizens in the world ...*".

Is this argument convincing? There is a well-founded fear that as long as climate change does not threaten the existence of our civilisation, the support of the world powers and the "rest of the world" for EU's actions against climate change will remain moderate, or perhaps only declaratory.

4. Will we see the era of the Sun and hydrogen in the near future?

Climate change, the rapid development of information technology (Internet of Things, Industry 4.0, Human Smart Cities), as well as the expected development of electromobility, will contribute to the development of ***Smart Energy Systems***, that is, the transition from large-scale energy generation to **distributed energy generation**.

This trend is confirmed by long-term forecasts of the use of primary energy sources. By analysing many of the available articles, materials of different companies and online publications [4–15], despite the sometimes contradictory nature of some conclusions, it seems reasonable to assume that in the long run (e.g. after the year 2050), the structure of primary energy consumption will fundamentally change (Fig. 5). In the next century, the Sun will become the most important source of energy for humanity. Are we then heading for the **Sun era**? If so, technologies associated with distributed power generation must become dominant and a transition from centralised to distributed energy generation is inevitable.

Forecasts and reports from official energy organisations such as IRENA (International Renewable Energy Agency) and IEA (International Energy Agency) [16–20] indicate that not only the switch to renewables will be crucial but also the improvement of efficiency and the switch to more electricity through the use of electric energy carriers. These changes are illustrated with the triangle shown in Fig. 6.

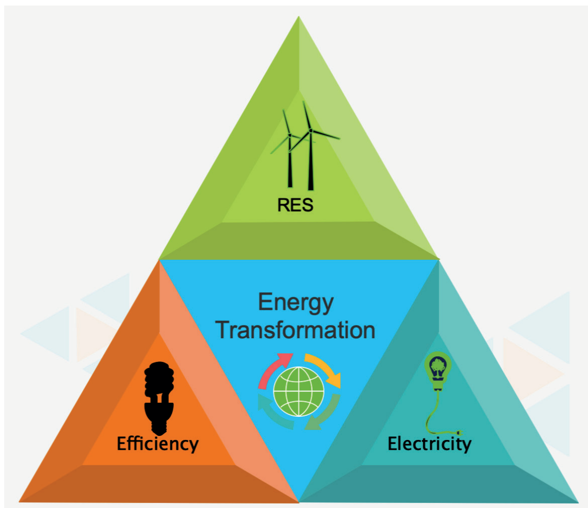


Fig. 6. The main three directions of global energy transformation: towards the use of RES, towards more efficient use of electricity and towards increased use of electricity

Thus:

Electricity combined with renewable energy is the essence of global energy transformation.

The above-mentioned synergy will not only directly contribute to the reduction of CO_2 emissions but also brings about beneficial social and economic changes, for example, by strengthening the role of prosumer and civic power engineering. Electricity combined with renewable energy sources indirectly increases energy efficiency and reduces global energy demand.

5. Hydrogen is the fuel of the future

It is worth paying attention to the role of hydrogen obtained from both renewable energy sources and fossil fuels. According to many forecasts, the share of hydrogen in the structure of the global consumption of primary energy sources will be dominant at the end of this century, although it is difficult to estimate this quantitatively [21].

Green hydrogen production from renewable electricity is expected to grow rapidly in the coming years. Today, the production of green hydrogen is relatively well known in technical terms. The problem of its cost-effectiveness remains. Today, the cost per unit of energy produced from hydrogen is 1.5–5 times higher than that of natural gas. This may change in the future.

The production of green hydrogen using electrolysis of water seems promising. Already now, in some countries (e.g. Germany), high-power electrolysers are being developed. Renewable hydrogen is undoubtedly the fuel of the future, although at present it is produced mainly from natural gas and coal (grey hydrogen – approximately 95%).

The existing business studies show that, depending on the location and service life of the electrolyser, *e-Hydrogen* could already be a market alternative at this point. However, this technology has a promising future due to the expected rapid decrease in production costs of electrolysers and the e-Hydrogen production process itself.

Therefore, *e-Hydrogen* has a chance to become the fuel of the future.

Hydrogen separation from natural gas without CO_2 emission, for example, using CCS (carbon capture and storage) technology and pipeline transport like **Nord Stream 2** seems to be faster for the time being, but hydrogen generation via electrolysis using RES is a more sustainable and promising solution.

In the near future, Poland may use blue hydrogen and transport it through the new gas pipelines such as the **Baltic Pipe** (for example, from Norway which is interested in the separation of this fuel from gas, from which carbon dioxide was already removed by means of CCS technology). This would be a transition from being dependent on the imported gas to being dependent on the imported hydrogen, but at least using a safe source.

According to current trends, it is reasonable to estimate that in 2040 electrolysis will be the cheapest way to produce zero-emission hydrogen. The hydrogen strategy is therefore taking a step in the right direction.

Hydrogen can also help to solve the problem of **energy storage**. Profitable energy storage in hydrogen fuel cells combined with renewable energy sources (e.g. on the Baltic Sea using **off-shore** technologies) would meet the expectations of green energy transformation advocates.

Poland has one of the best access to **natural hydrogen reserves** in the form of **salt caves**. With a good hydrogen strategy, we have the potential to develop energy storage facilities with the lowest costs in Europe.

When summarising the issues tackled in this chapter, one can conclude that the next century in the life of our civilisation will be the **era of the Sun and hydrogen** — in other words, figuratively speaking, there will be a **yellow-blue transformation** (provided that the yellow colour represents the Sun, and the blue colour represents hydrogen).

And this, in turn, would provide an answer to the questions: Quo Vadis power engineering? Is it possible that humanity has finally found the **Holy Grail** of power engineering?

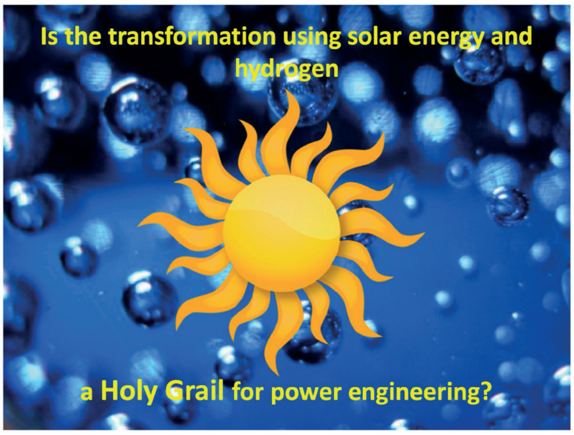


Fig. 7. Is the yellow-blue transformation using solar energy and hydrogen a Holy Grail for the energy sector and our civilization?

6. Civic power engineering based on DES/RES technologies

The energy transformation and growing use of RES will introduce new users on the market: citizens, municipalities, and cities. This may change the structure of political and economical power as renewable energy sources tend to decentralise and democratise energy systems.

We are talking here about **prosumer power engineering** (where the citizen is both a consumer and producer of energy), and in a broader sense about **civic power engineering**, which is the essence of off-grid renewable energy systems.

These changes will create a more diverse energy ecosystem. The role of the centralised state can change in such a system. Many new investors and new business models will emerge. Local and distributed energy sources give households and communities more autonomy than centralised network systems.

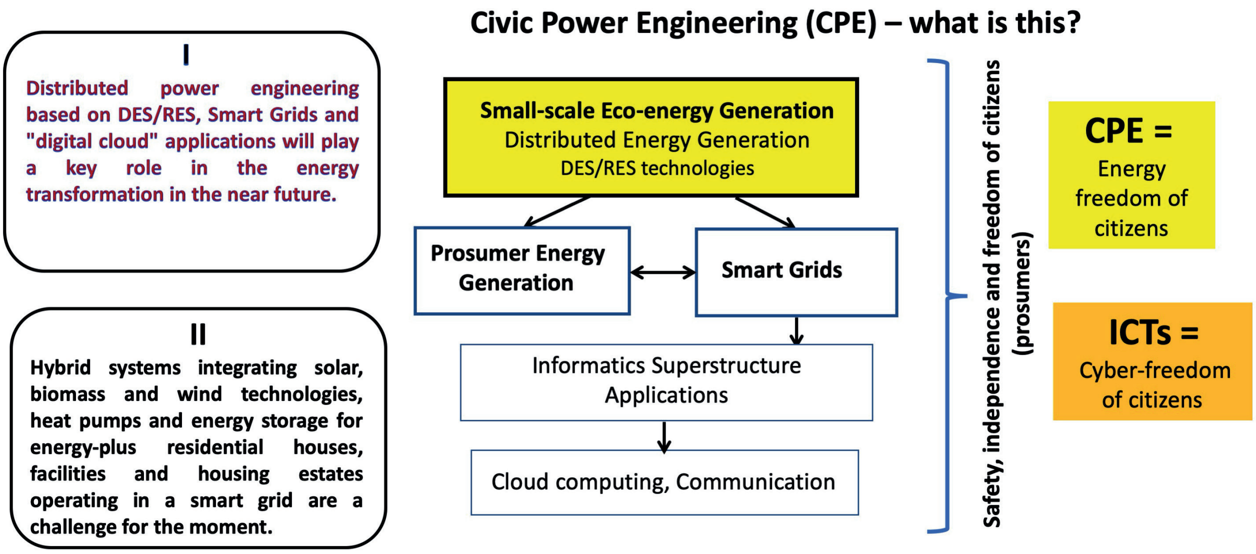


Fig. 8. Civic power engineering, based on DES/RES technologies, is the key element in the energy transformation; DES – distributed energy systems, RES – renewable energy sources

Distributed energy systems (**DES**) that use renewable energy sources (**RES**) — in short, **DES/RES** — will play a key role in this regard. The term DES/RES basically refers to the technology, and **civic power engineering** (**CPE**) seems to be a broader term [22–25].

Typical DES/RES technologies generally use several methods of generating electricity and heat as well as storing and managing energy. These are therefore the most economically profitable **hybrid technologies** available in different configurations.

On the other hand, civic power engineering, in its broadest sense, means the energy freedom of citizens, just as information and communication technologies (ICTs) once meant the cyber-freedom of citizens (Fig. 8).

7. What energy mix should we choose for Poland?

Let us now return to the most important issue related to the transformation. In light of such controversies and difficult dilemmas, the questions remain: What energy mix should we choose for Poland? What decision should politicians and companies make in this matter?

It should be clearly stated at the outset whether we are talking here about **the most likely** mix, which may take place in the next few decades in Poland, or about the mix **desired** from different points of view. The analysis of different types of scenarios and opinions has shown how much they differ depending on what organisation or experts developed them.

Considerations towards the most likely mix for Poland, for example, for the next two decades, should be based on the following several factors:

- The national specificity of different industrial sectors, especially the role of coal and the political conditions connected with it. This fact cannot simply be omitted despite the suggestions of some experts and scientists. Obviously, this fact cannot be ignored by politicians either.
- The scenarios developed by the government, which are supported to a significant extent by the opinion of scientists from the Committee for Power Engineering Issues of the Polish Academy of Sciences, naturally have an advantage over other scenarios (constructed by international organisations or independent experts) because the governmental side has the so-called "*driving force*", and moreover many of these opinions concern the general situation in the world or Europe, and not specifically Poland.
- Long-term scenarios (going beyond 2050) which can be burdened with too many errors and can only be treated as a guide rather than reliable data.

It can, therefore, be assumed with a high degree of probability that coal and gas, i.e. **fossil fuels**, **will remain the main source of electricity in Poland** for the next two decades. Only the proportions will change because in 2040 many more the so-called zero-emission sources (i.e. photovoltaics, off-shore wind farms and nuclear energy) will be used. It is worth noting that the relative share of fossil fuels in electricity production in 2020 is about 80% and in 2040 it is expected to be only 60%. However, this proportion in absolute terms remains practically at the same level.

In Poland, the electric power system will therefore be composed of two systems: a system **with emission**, with about 40 GW of installed capacity in 2020; and a system **without emission** with similar installed capacity in 2040 (photovoltaics, biomass, and gas – about 20 GW, off-shore wind farms — 8–10 GW and nuclear power engineering – 6–9 GW). Figure 9 presents the most likely version of the energy mix for Poland by 2040, divided into two systems: with emission and without emission. It is worth noting that almost the entire increase in electricity production in the next two decades, i.e. from about **40 GW** (conventional installed capacity) to about **76 GW** in 2040, results from the use of an emission-free power system.

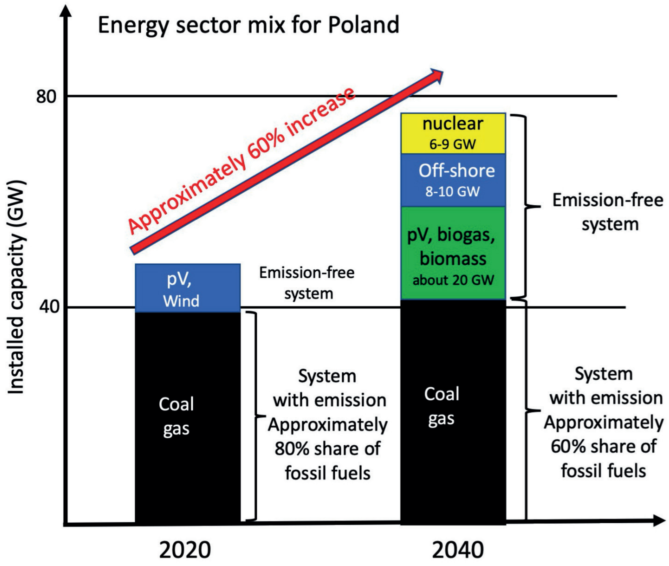


Fig. 9. The most likely energy sector mix for Poland by 2040; although fossil fuels will remain the main fuel used to produce electricity, their relative share will decrease from 80% to 60%; two systems will coexist, complementing each other synergistically: the traditional emission-based system and the emission-free system

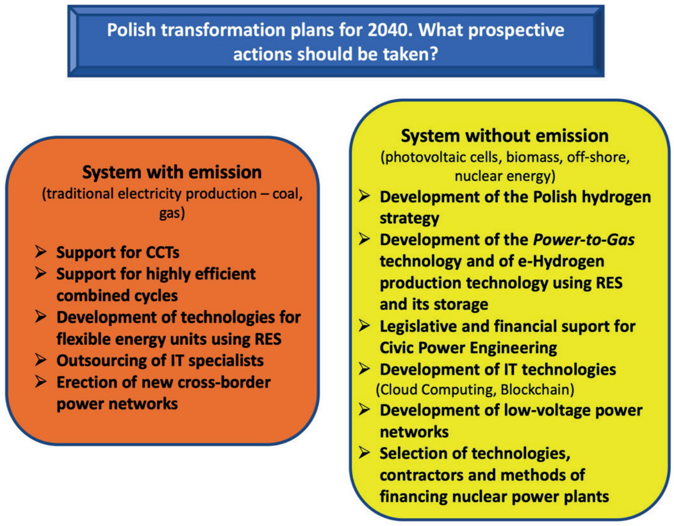


Fig. 10. The most urgent actions if a probable version of the energy sector mix is implemented by 2040; CCT – clean coal technology

This means that in 20 years' time Poland is planning to build a second alternative emission-free system with a capacity comparable to the conventional capacity installed today. Therefore, two systems will operate in synergy in our energy mix.

How can this be achieved? The most controversial are the plans to build nuclear power plants. The planned capacity of 6–9 GW is strongly contested by many experts. And it is not just about the protests of environmentalists and public recognition of a potential threat of a catastrophe and contamination, but simply about the investment costs, and especially about finding a contractor and an optimal credit package. After all, such huge investments cannot be financed from the state budget. Poland is not one of the richest countries in the world, therefore there are so many opinions about a complete resignation from building a nuclear power plant. For this money, several highly efficient conventional power plants could be built, which can provide many more jobs for Polish specialists and workers.

The discussion on this issue is still ongoing and there are no concrete, final decisions.

As for the other elements of an emission-free system (especially photovoltaics, biogas, biomass, and offshore wind energy), their use on such a large scale will require **breakthrough solutions** on **a local level**.

7.1. What prospective actions should be taken? On a local level, those may be energy clusters or municipal energy centres, i.e. simply elements of **civic power engineering** based on distributed energy systems and renewable energy sources, in short, DES/RES (Fig. 8).

DES/RES systems can be commonly built by citizens or communities with the legislative and financial support of the state, thus creating, de facto, a system of small, dispersed power plants. The most urgent actions within the framework of the energy sector mix described are summarised in Fig. 10.

Summarising the discussion on the Polish energy sector mix in the next two decades, it should be noted that it differs quite significantly from the scenarios presented by various international agencies such as IRENA and IEA or by many experts and scientists. It also differs from the objectives presented in the European Green Deal [16–20].

In these scenarios, the focus on renewable energy and climate protection is much greater, arguing that climate-oriented sustainable development is both possible and beneficial if certain conditions are met.

Poland, as we know, has negotiated its own path to climate neutrality in the European Union, and the mix shown in Fig. 9 is a result of this.

Speaking of the energy sector mix for Poland, it is necessary to raise the issue of transformation costs. Poland has a specific electricity production structure. As much as 77% of electricity is produced from hard coal and lignite, only 7% from natural gas and 13% from renewable energy sources. At the same time, only 58% of the country's territory has access to gas. This is why most the commonly used private heating systems are coal stoves, which are often old generation devices called "**kopciuchy**" in Polish. This, in turn, causes high air pollution — as many as 33 out of 55 European cities with the highest air pollution are located in Poland.

According to the European Commission, the energy transformation in Poland will cost our country as much as **EUR 240 billion**. The Polish government is working to ensure that the Just Transition Fund (JTF) invests both in moderating the effects of the transformation and in its implementation.

7.2. Role of natural gas. Polish e-hydrogen. Natural gas can play an important role in the Polish transformation. As gaseous fuel does not fall into the category of renewable energy sources, it is referred to as a transitional fuel on the way to the full energy transition. The European Commission underlines that the transition towards climate neutrality will rely on a wide range of energy sources and technologies and the role of natural gas is important as a transition fuel. The demand for gas is constantly growing. In 2018, the global share of natural gas demand was **24%**. According to the International Energy Agency's forecasts, by 2040, global demand for natural gas will have increased to almost **40%**.

The demand for natural gas will grow faster than the demand for oil, which reflects, among other things, the ongoing trend of promoting cleaner energy sources. The large rapid growth of the gas market also brings new investments ensuring new directions of supply. The Baltic Pipe project, which aims to create a new route for the supply of natural gas from Norway to the Danish and Polish markets as well as to end-users in the neighbouring countries, is obviously of strategic importance. The pipeline will be able to transport 10 billion m^3 of natural gas annually to Poland and 3 billion m^3 of gas from Poland to Denmark. The construction works phase is expected to start in 2020, which will allow the import of natural gas from the fields located on the Norwegian Continental Shelf.

Bulgaria, the Czech Republic, Greece, Lithuania, Poland, Romania, Slovakia and Hungary have prepared a *non-paper* in which they claim that gas will be, from their point of view, an essential tool to achieve climate neutrality in the European Union in 2050 (see: the website *biznesalert.pl* at *https://biznesalert.pl/polska-koalicja*). This implies a coalition between Poland and these countries to defend the role of gas in the EU's climate policy.

If the Polish Hydrogen Strategy were more advanced, then it would be possible to imagine the best variant of emission-free power engineering with a perspective for the next two decades, namely a variant based on the **power-to-gas** technology.

This means that mainly electricity from large **off-shore** wind farms, but also from large on-shore and photovoltaic installations, would supply high-power electrolysers, which in turn, by producing hydrogen, and more specifically **e-hydrogen**, would ensure the storage of produced energy and its further stable use in both local off-grid systems and large-scale on-grid systems (Fig. 11).

Power-to-gas technologies or, more broadly, power-to-X technologies are the most promising directions for the development of emission-free power engineering, not only in Europe but also in other parts of the world.

Poland, with its great off-shore and on-shore potential and rapid development of photovoltaics, can play a significant role in the development of these technologies.

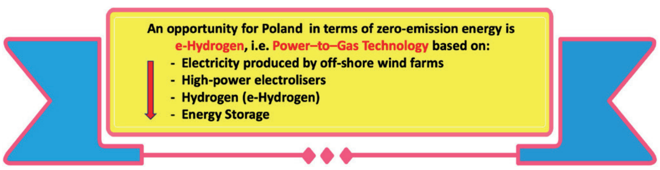


Fig. 11. The e-hydrogen and power-to-gas technologies (where electrical energy is produced mainly by offshore wind farms) may be an opportunity for the development of emission-free power engineering in Poland

8. What can science propose? Examples of innovative technologies

8.1. Prosument model of a rural municipality. Energy map. We will limit ourselves here to a few examples of new technologies in the field of civil power engineering, which are being developed at the Institute of Fluid-Flow Machinery of the Polish Academy of Sciences in Gdańsk. It is an example of a scientific contribution to the Polish energy transformation [26–32]. The author of this article, as the director of the institute and manager of several large research projects, feels competent for this kind of evaluation, but only in terms of the contribution that the institute has made.

Within the framework of the strategic project TechRol (BIOSTRATEG III), coordinated by IMP PAN (with the author of the article as manager of the project), a prosumer model of a rural municipality and the requirements for a low-emission agricultural production are being developed. Therefore, this project fits perfectly into the concept of civic power engineering, which was described earlier, all the more so as the subject matter of the project also includes the issues of smart management of energy resources, energy mapping and selection of appropriate RES technologies. The technologies developed within the framework of the project are being tested on a real site which is the Municipality of Przywidz located in the Kaszuby region. This municipality is therefore a partner in the project (Fig. 12). Developing a prosumer model of a rural municipality requires the implementation of many tasks such as determining the amount of demand for heat and electricity in the municipality, and thus conducting an **energy mapping** process.

Fig. 12. Research Object – the municipality of Przywidz located in the Kaszuby region in the Pomeranian Voivodeship

Another important task is to develop a **smart system** for **managing** the production and consumption of energy carriers. This will help to simulate virtual energy systems and optimise the use of available resources.

Based on the data received from the municipal authorities and the distribution network operator, an analysis of the measurement data was carried out, the description and evaluation of the municipal power network were performed, and as a result, a multidimensional analysis of the obtained measurement data was carried out (generally and in detail for particular groups of recipients).

Figures 13 and 14 present some examples of results related to the classification of buildings, consumers, and energy consumption in the Przywidz municipality. Figure 13 shows that statistically in a municipality in Poland, the share of households taking part in the energy market is on average about 20 per cent. The analysis conducted for the rural municipality of Przywidz shows that the share of households (tariff group G) in the total municipality's energy consumption is 54%. Such a big difference stems from the specificity of the municipality – it is a **rural municipality with a low level of industrialization**, and therefore perfectly suited for low-emission agricultural production.

Figures 15 and 16 show an example of how to optimise energy installations in a given building, in this case in the **Arena Przywidz** building.

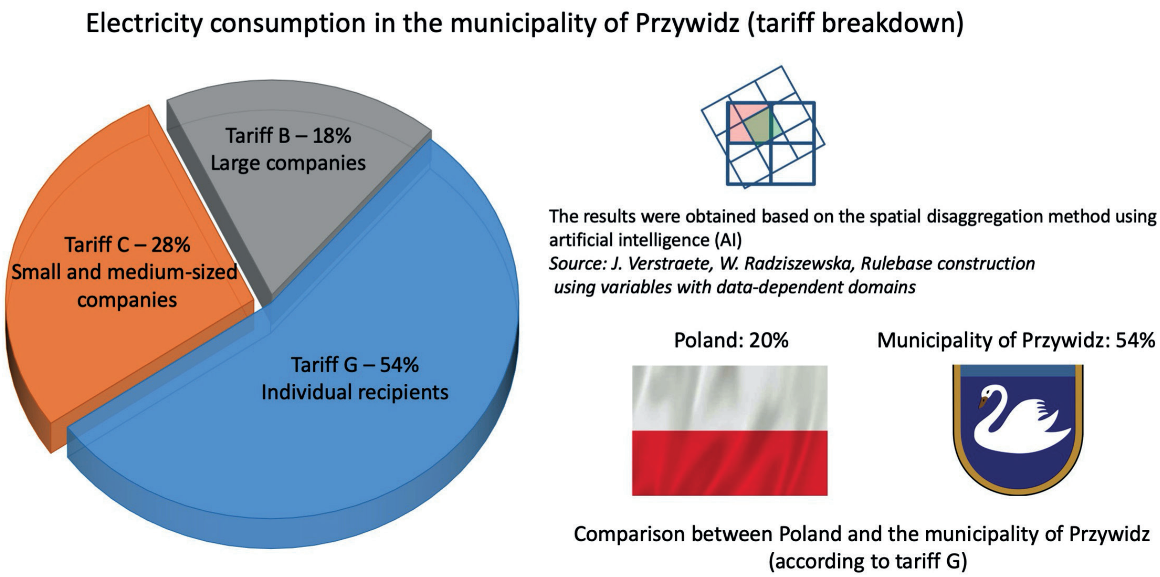


Fig. 13. Elements on energy map: energy consumption with a breakdown into tariffs – according to the results of the study carried out by Dr W. Radziszewska and her team

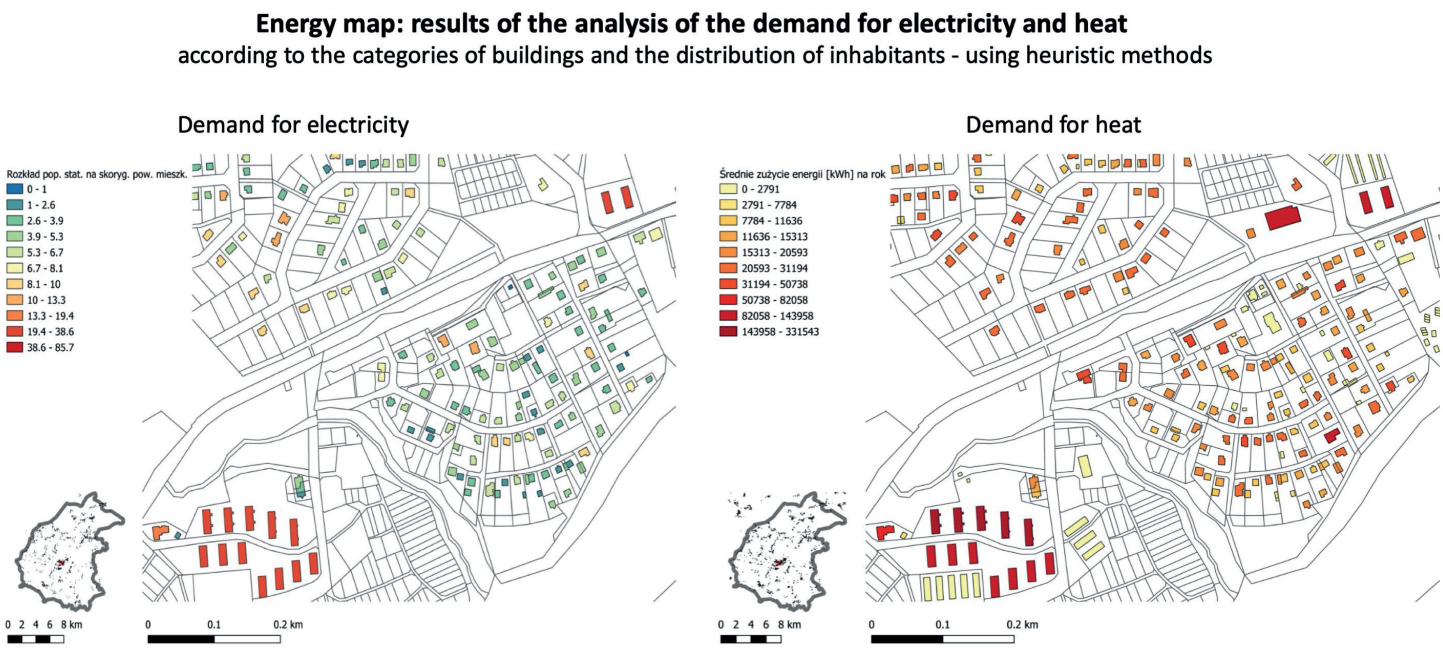
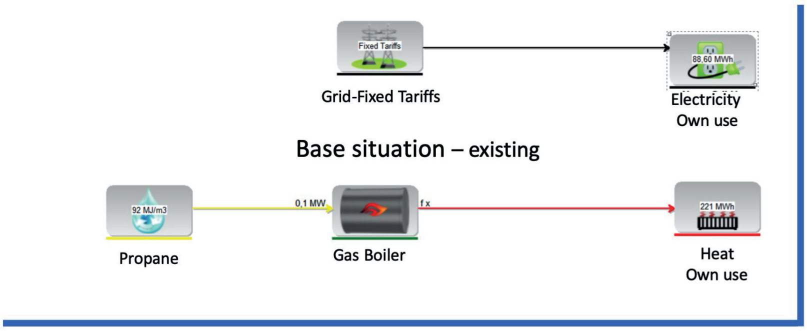
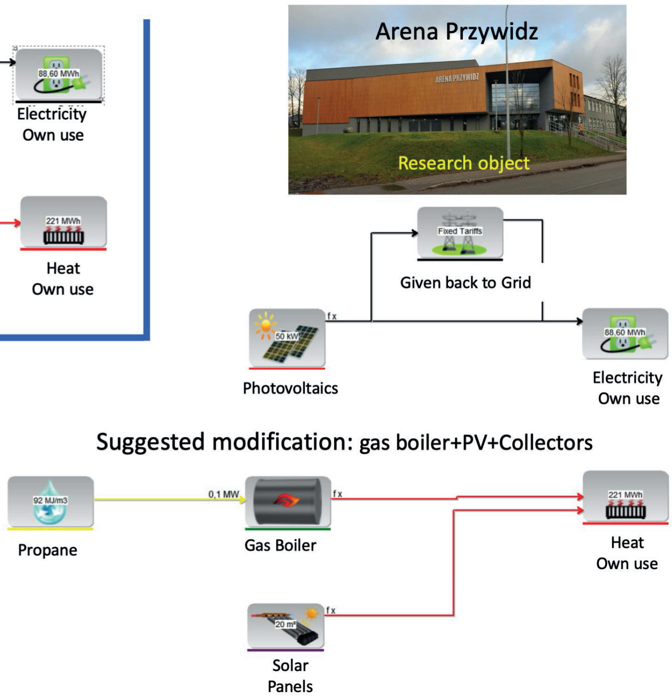


Fig. 14. Elements on energy map: demand for energy – according to the results of the study carried out by Dr W. Radziszewska and her team





Analysis Results EnergyPRO Program	Existing situation	Suggested modification
	Gas Boiler	Gas boiler Photovoltaics Solar panels
Heat produced from renewable energy sources	0 MWh	11.5 MWh
Electricity produced from renewable energy sources	0 MWh	51.1 MWh: 25.5 MWh for own use 25.6 MWh given back to grid
Annual maintenance cost	112,457.00 PLN	94,671.00 PLN
Difference in maintenance costs	-	**- 16%**

Fig. 15. A proposal to modify the thermal and electrical installation located in the Arena Przywidz building; the table shows the results of calculated operating costs for the version without and with modification – the use of collectors and photovoltaic panels brings a profit of about 16% – based on the results of the study carried out by M. Jaroszewska and P. Chaja

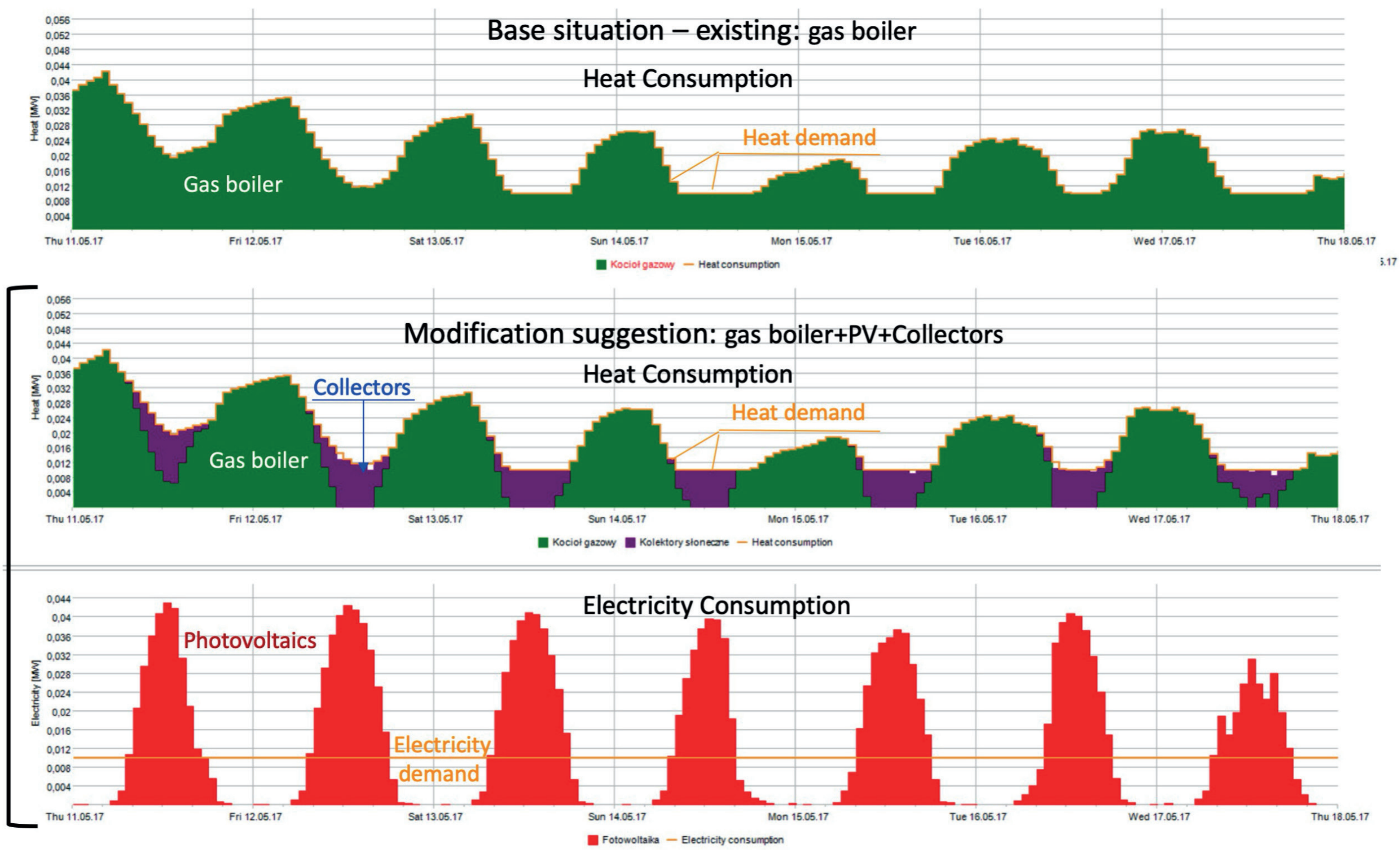


Fig. 16. Calculation results of thermal and electrical power distribution versus the days of operation, shown in relation to the building's energy demand; upper graph – existing heating installation (gas boiler only), Middle and lower graph – calculations considering modifications (collectors + pV) – based on the results of the study carried out by M. Jaroszewska and P. Chaja

The calculations were carried out using the energyPRO program, which is produced by the Danish company EMD. This program was purchased as part of the TechRol project and the skills to use it were acquired thanks to scientific internships and through the cooperation of IMP PAN's staff with both EMD and Danish universities.

This software is used to carry out technical and economic analyses as well as to optimise cogeneration and trigeneration projects. It also facilitates creating other complex energy projects together with the use of electricity and heat from different energy generating units.

EnergyPRO optimises a given energy project based on technical and financial parameters. Thanks to this optimisation of the system's operation, it is possible to determine an exact amount of the supplied energy (heat, cooling, and electricity) according to demand. This program makes it possible to carry out technical and economic analyses for many different types of systems, such as combined heat and power plants with gas engines connected to boilers and accumulating vessels, cogeneration installations or solar installations.

The proposed modification of the energy system located in the Arena Przywidz building is shown in Fig. 15. The existing heating system with propane tanks and a gas boiler is recommended to be complemented by solar and photovoltaic panels with the possibility of feeding electric energy surpluses to the power grid.

The results of computer calculations for such a combination are shown in Fig. 16. They indicate that it is possible to reduce the operating costs of the building's energy system by 16% (see the table in Fig. 15).

8.2. Computer system for managing energy resources in the municipality. Within the framework of the TechRol project, the BLUETOMATION company (Edyta Wołczyńska's team) is developing an original computer system for managing energy resources in the municipality. It provides support for municipalities on how to produce and use electrical, thermal, and gaseous energy on their territory and on how to install new elements in the network. The computer system that is being developed allows collecting measurement data and simulating changes in the power network, with a particular focus on the collection, storage, transformation and use of biomass in accordance with the law.

A municipality deciding to implement all modules of this system receives a tool which can help to design changes in its entire power network (not only in its electrical parts) in a relatively fast and cheap way, in order to adapt it to the upcoming challenges. This makes it easier to plan the modernisation of the existing elements of the energy network (e.g. school boiler room) by adding new devices that produce and consume energy.

Figures 17 and 18 describe the main modules of the computer system that is being designed.

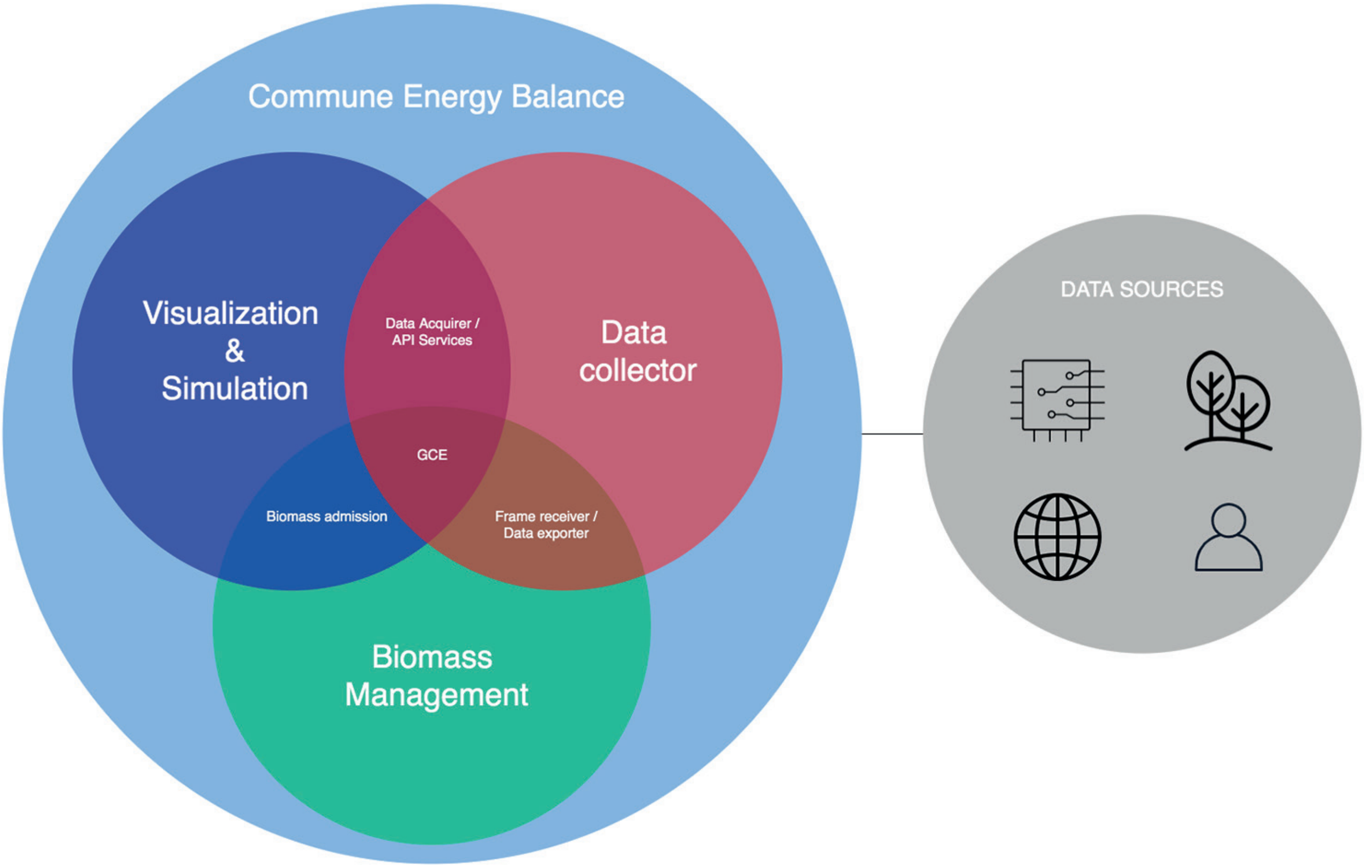


Fig. 17. Main modules of the computer system designed to manage energy resources in the municipality – diagram by E. Wolczyńska with team

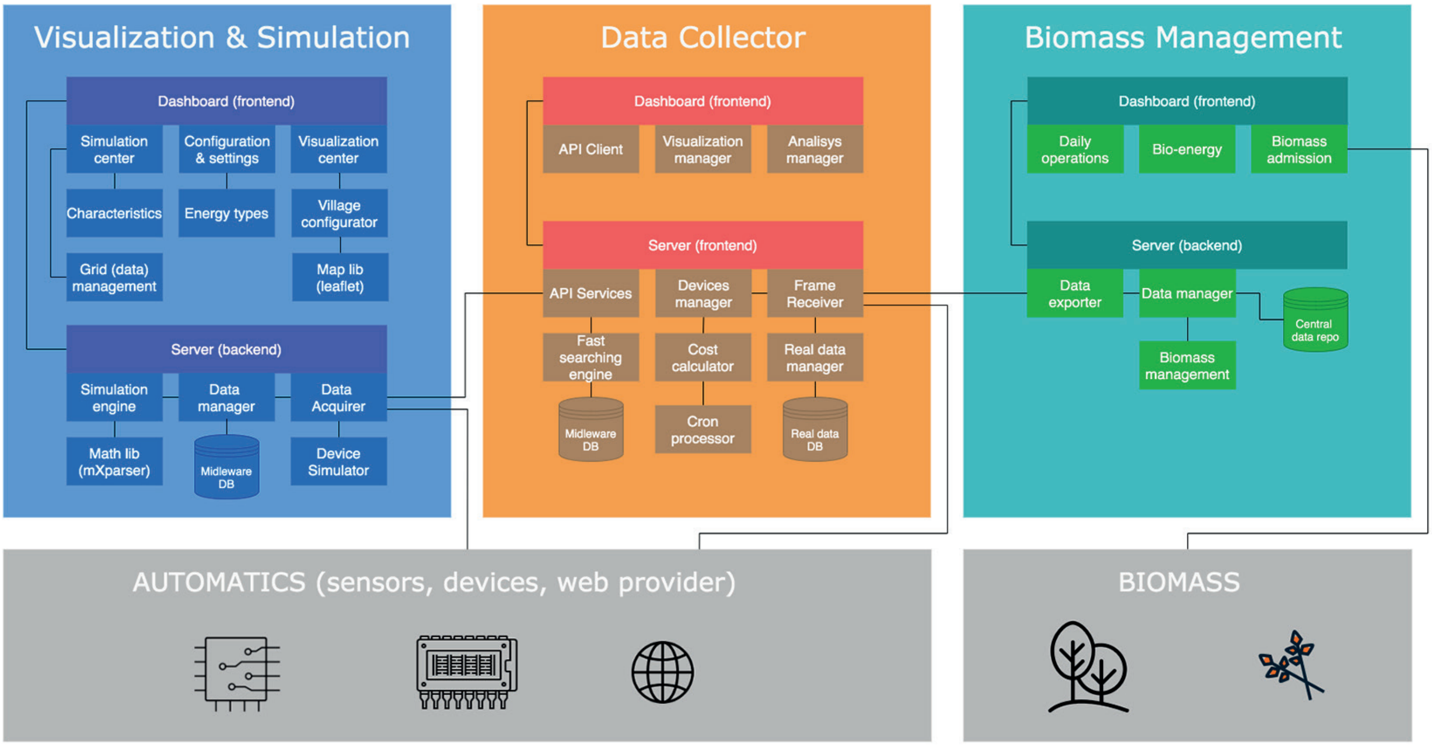


Fig. 18. More detailed description of system modules – diagram by E. Wolczyńska with team

8.3. Microturbines in food production. Microturbines that operate with low-boiling mediums (ORCs) are a good and common solution when it comes to using **waste heat** from combustion engines or various technological processes in factories (e.g. cement plants, refineries, food factories, etc.).

It can be expected that there will potentially be a large number of buyers on the Polish market willing to use cheap fuel to produce electricity for their own needs. This means that the series of microturbines developed at IMP PAN, as an important element of **civic power engineering**, has a chance to become an innovative technology commonly used in Poland. One example is an ORC cogeneration system with a 10 kW microturbine, designed to use waste heat from a food production process. It is planned to use waste heat from the food roasting production line in a plant producing decaffeinated beverages based on cereals and chicory. The pilot installation will be connected with the chicory roasting line, where the outlet gas temperature is approximately 300°C (Fig. 19).

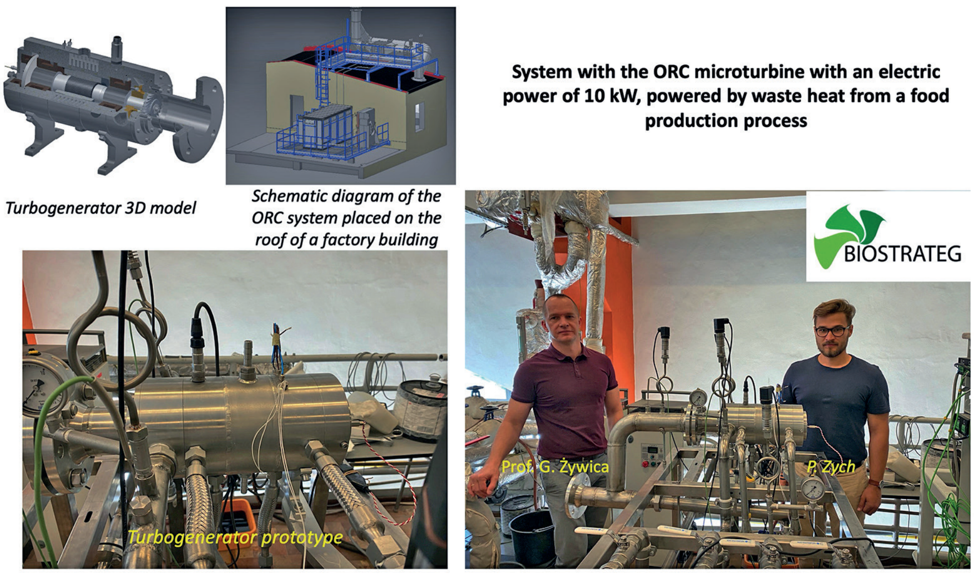


Fig. 19. ORC microturbine system that uses waste heat from the food production process; works carried out by Professor G. Żywica's team

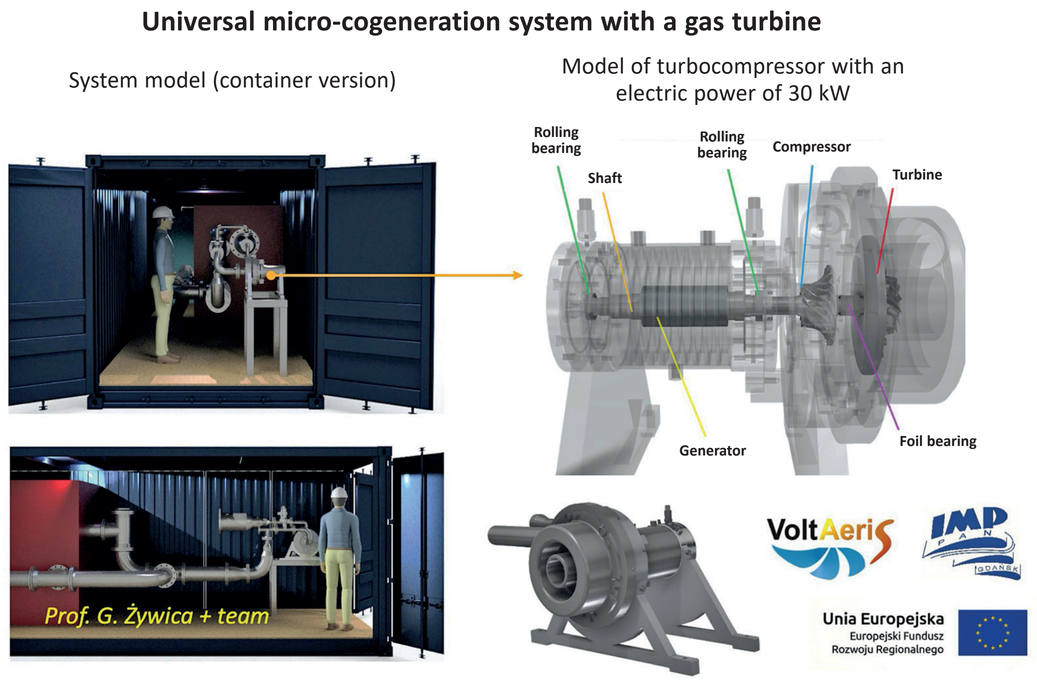


Fig. 20. Gas turbine that is driven by hot air, designed to produce heat and electric energy of up to 30 kWe using biomass or coal – works carried out by Professor G. Żywica's team

The low-boiling medium used is non-flammable and safe for the environment. Thanks to such a solution, the ORC system will not interfere in any way with the production process and will not have a negative impact on it. The benefits of using an ORC cogeneration system include the possibility of generating own electricity (up to 50,000 kWh per year) and managing waste heat for own needs.

The direct benefit for the environment is that the temperature of the outlet gas is significantly reduced (by about 150°C).

The Polish and global market currently lacks devices that would be able to produce electricity on a small-scale using cheap and widely available solid fuels; solid fuels are currently used only in large power plants and ORC systems with capacities well over 150 kW. On the other hand, commercially available micro-cogeneration systems are powered either by gas or liquid fuels.

The IMP PAN proposes solutions — in the form of small, universal gas turbine systems — which have a chance to become an innovative technology that allows producing electricity from fuels that are currently used, at the very most, for heat production (Fig. 20).

8.4. Syngas purification. The purification of syngas from pollutants so that it can be used in piston engines is one of the key issues when it comes to gasification processes occurring in cogeneration systems. As part of the TechRol project (Biostrateg III), purification methods that use water or oil gas scrubbers, as well as **plasma-based purification methods**, are being developed at IMP PAN. Figure 21 shows the photograph of the "GlidArc" discharge taken during research into the effectiveness of syngas purification.

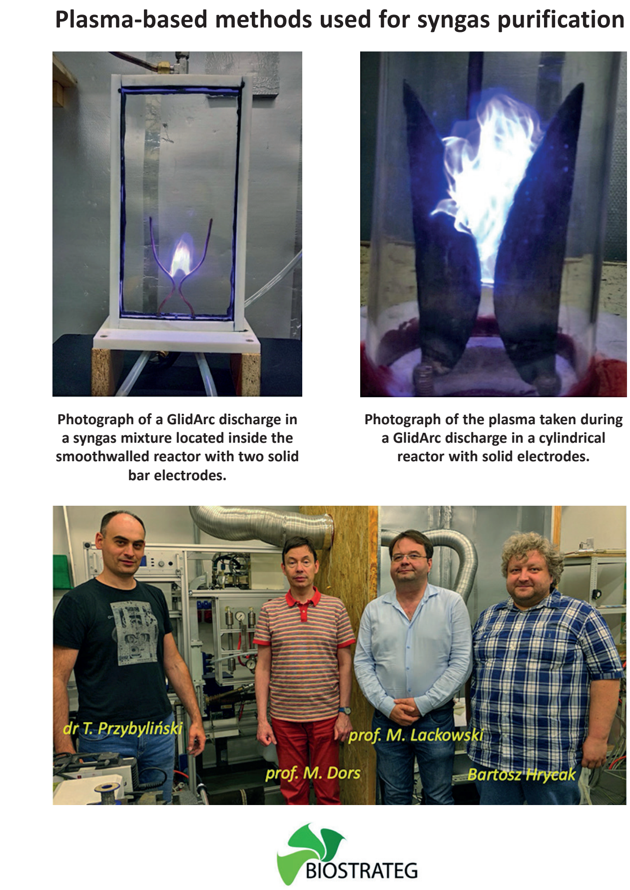


Fig. 21. One of the syngas purification methods developed at the IMP PAN: concept of plasma use; works carried out by Professor M. Lackowski's and Professor M. Dors' teams

8.5. Hybrid energy storage systems. A conventional approach to energy storage involves the use of only one selected technology in the electricity storage system. It is usually selected to perform one function. A hybrid storage unit combines two or more technologies in one system. Such a solution makes it possible to optimise the efficiency of the energy storage system if it is to fulfil many functions. For the user, this means the possibility of extending the machine lifetime and increasing the benefits and profits obtained from the installation of an energy storage system.

The benefits of the use of a hybrid energy storage system are determined by the way it is controlled.

Within the framework of the ***HyStore*** project which is being implemented at the KEZO Research Centre in Jabłonna (IMP PAN's branch office), an energy management system dedicated to these types of energy storage facilities will be developed. Optimisation algorithms will be used to maximise profits generated by energy storage systems.

Currently, a demonstration installation of a hybrid energy storage system is operating at the KEZO Research Centre. This system is part of a functional micro energy network composed of renewable energy sources, energy-consuming devices and charging stations for electric vehicles. The hybrid energy storage system uses the following batteries available on the market: flow-through, lithium-ion and lead-acid batteries (Fig. 22).

The hybrid energy storage system uses a unique **flow-through battery**, which has been installed at the KEZO Research Centre in Jabłonna. As a result, the first Polish microgrid with a flow-through battery has been built, which integrates a heating system, a cooling system, and an electric power system (Fig. 22).

9. Conclusions

The examples of technologies and installations presented in the article are the utilitarian result of some of the projects which are being carried out at IMP PAN, which focus on environmentally friendly power engineering. These projects reflect the contribution of the Institute and its collaborating research teams from other scientific centres to the national effort connected with **green energy transformation**. After analysing the results obtained, the author of the article would like to risk a statement that the Institute has contributed, to some extent, to the creation of conditions required for the development of prosumer power engineering (or more broadly: civic power engineering) in our country. Civic power engineering is a great vision in which the citizen becomes an entity and is not subject to the energy market, and additionally has a virtual advisor in the form of smart grid and data processing technologies in a "digital cloud".

Therefore, it can be concluded that distributed power engineering based on DES/RES technologies, Smart Grids, and digital cloud" applications will be an important element of

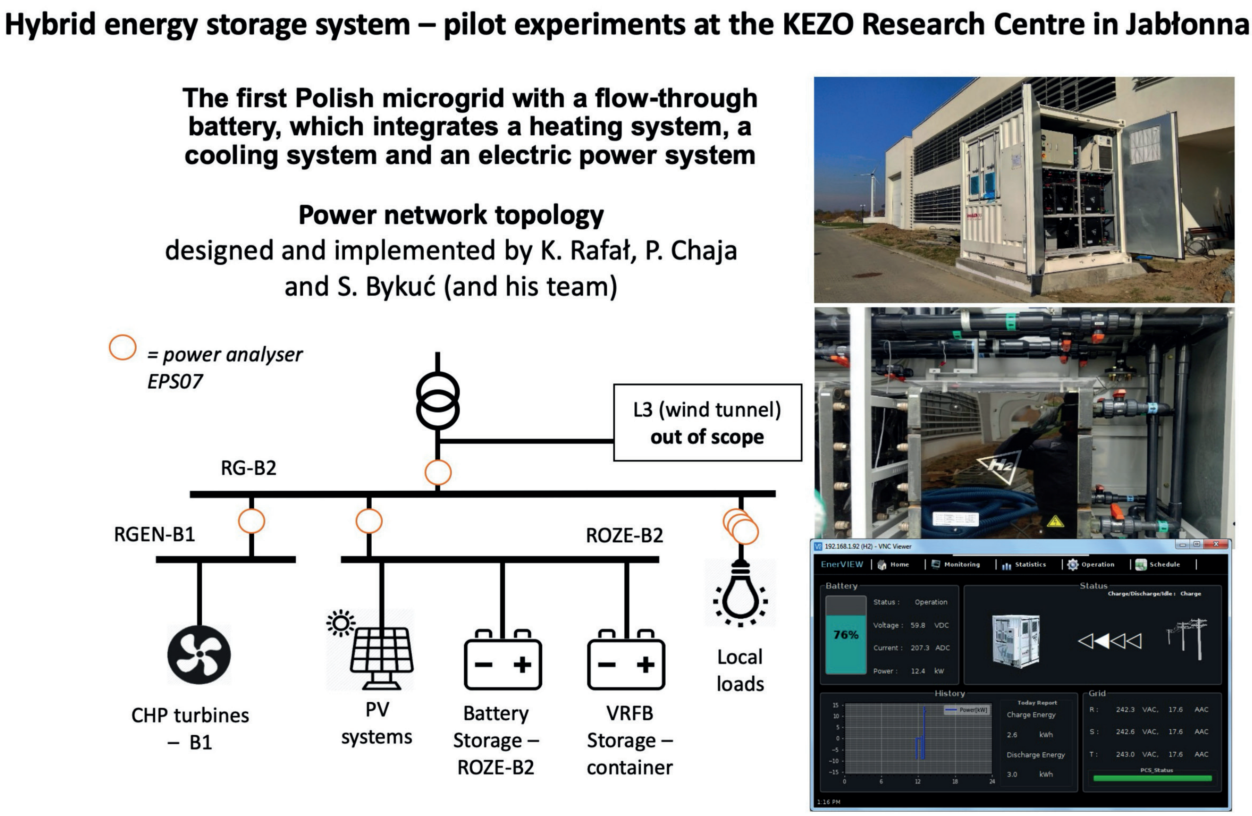


Fig. 22. Unique installation in Poland: micro power network with a flow-through battery, based on a hybrid energy storage concept (on the basis of the results of the study carried out by K. Rafał and W. Radziszewska)

the state energy policy in the near future. This means that the hybrid systems integrating solar, biomass and wind technologies, heat pumps and energy storage for energy-plus residential houses, facilities and housing estates operating in a smart grid are a challenge for the moment.

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