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Battery energy storage utilization in optimization of heat production in district heating sector

Wykorzystanie bateryjnych magazynów energii do optymalizacji produkcji ciepła w ciepłownictwie

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Keywords: *heat, electricity, storage, energy, optimization, battery, electrochemical, innovation*

Abstract

The innovative approach to the issues of integration of an electricity storage, heat storage and an electrode heating boiler in the heating system in this paper is presented.

In recent years, a growing share of renewable energy sources in heating has been observed, which may result in the dynamics of electricity price variability being greater and more frequent than in daily and annual periods. This may apply in particular to the price of heat from electrode boilers. The proposed solution to optimize heat prices at an acceptable level for end users, consisting in connecting an electrode heating boiler with heat and electricity storage facilities is presented.

Słowa kluczowe: *ciepło, energia elektryczna, magazynowanie, energia, optymalizacja, bateryjne, elektrochemiczny, innowacja*

Streszczenie

W artykule przedstawiono innowacyjne podejście do zagadnień integracji magazynu energii elektrycznej, magazynu ciepła i elektrodowego kotła ciepłowniczego w systemie ciepłowniczym. W ostatnich latach można zaobserwować rosnący udział odnawialnych źródeł energii w ciepłownictwie, co może spowodować, że dynamika zmienności cen energii elektrycznej będzie większa i częstsza niż w okresach dobowych oraz rocznych. Może to dotyczyć w szczególności ceny ciepła z kotłów elektrodowych. W artykule przedstawiono propozycję rozwiązania dla optymalizacji cen ciepła, na akceptowalnym poziomie dla odbiorców końcowych, polegające na połączeniu elektrodowego kotła ciepłowniczego z magazynami ciepła i energii elektrycznej.

1. INTRODUCTION

The EU energy system is undergoing a profound transformation, characterised by i.a. an increasing share of renewable energy sources, more players and more decentralised, digitalised and interconnected systems. This offers new opportunities to the energy sector but also new challenges, including in the current context of high energy prices. The EU objective is to become climate neutral by 2050, with an intermediate target of a 55% net reduction of greenhouse-gas emissions compared to 1990 levels by 2030. The European Green Deal laid down the strategy to achieve this objective, reinforced in the Fit for 55 package, which was turned into a legal obligation by the European Climate Law. The production and use of energy account for more than 75% of the EU's greenhouse-gas emissions, and decarbonising the EU's energy system is therefore critical to reach these climate objectives [2]. Members States (MS) are obliged to follow EU regulations in that matter and strategies to climate neutrality in MS strategies and policies can be found as well as in strategies of leading power companies Europe-wide. Energy storage systems allow energy consumption to be separated in time from the production of energy, whether it be electrical or thermal energy. The storing of electricity typically occurs in chemical (e.g., lead acid batteries or lithium-ion batteries, to name just two of the best known) or mechanical means.

Thermal energy storage systems can be as simple as hot-water tanks, but more advanced technologies can store energy more densely (e.g. molten salts, as used in concentrating solar power, ATES).

With the rapidly falling costs of solar and wind power technologies, increasing shares of variable renewable energy will become the norm, while efforts to decarbonize the heating sector are being accelerated by EU regulations like Fit for 55 package, EU Taxonomy Regulation [3], [4]. This need to accommodate variable energy supply while providing undisrupted output in the electricity sector, as well as efforts to integrate renewables into the end-use sectors has brought into sharp relief the significant potential, as well as crucial importance, of electricity and heat storage to facilitate deep decarbonisation.

Heat and electricity storage that is based on rapidly improving batteries and other technologies will permit greater flexibility in heat production with reasonable heat price, a key asset as the share of variable renewables increases [9].

The district heating sources usually rely on primary source like combine heat and power (CHP) unit and reserve-peak heating only boilers (HOB). But the environmental changes and decarbonisation goals require the redesign of future configuration of heat sources in district heating plant. The combination of various storage systems

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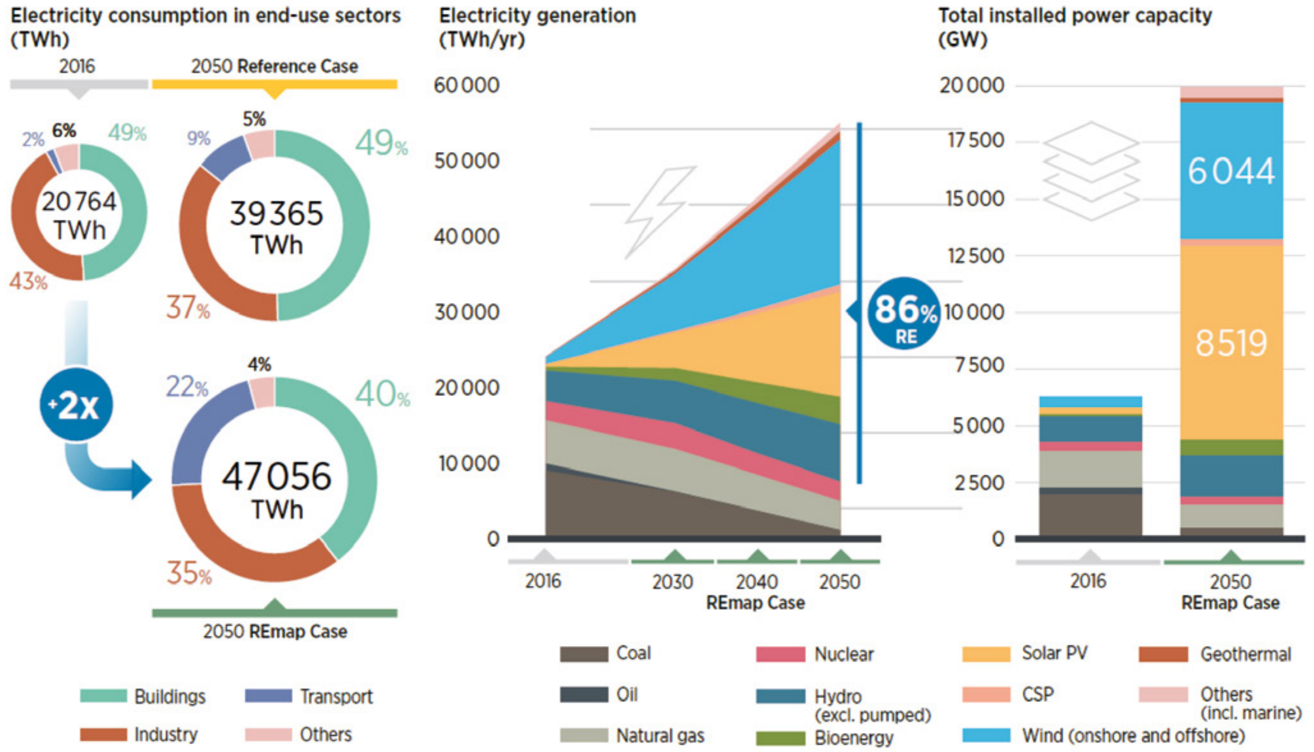

Fig.1. Electricity generation mix and power generation installed capacity by fuel, REmap case (IRENA's Renewable Energy Roadmap), 2016–2050 [7]

Rys.1. Mix wytwarzania energii elektrycznej i mocy zainstalowanej wg paliw, scenariusz REmap (IRENA Mapa Drogowa Energii Odnawialnej), 2016-2050 [7]

in district heating together with electrode boiler can be the response for the regulatory, electricity and heat markets changes. This innovative approach for the nouvelle heat source, backed up with storage is the solution for optimization of economy account due to better management of production units and can also lead to better design of investments.

2. European Union Regulations

The impact and support in energy storage can be found in number of EU regulations and funds that support the energy storage development. The energy storage is a crucial part of the power sector because important regulatory services for the system operator, particularly frequency stabilization, reactive power compensation, Demand Side Response (DSR) services, additional capacity, black start service, peak demand coverage, blackout protection, etc. can be delivered.

A comprehensive European approach to energy storage is stated in European Parliament (EP) resolution of 10 July 2020 (2019/2189(INI)) [3]. The importance for this passage is both electrochemical storage, heat storage and the role of decentralised storage. According to EP resolution there is potential for energy storage growth as battery technologies will play an important role in ensuring a stable and flexible electricity supply.

Battery technologies are of crucial importance to guarantee the EU's strategic autonomy and resilience as regards electricity supply, due to access to electricity and flexibility markets.

Heat storage (such as large-scale boilers) and district heating in densely populated areas is very efficient tool for energy storage providing the necessary flexibility to integrate a greater share of intermittent renewables and waste heat from industrial processes and the tertiary sector.

Flexible cogeneration provides a forward-looking integrated energy storage solution for flexibility of electricity grids and efficiency of heat supply thanks to heat storage decoupling electricity production from heat consumption.

The energy storage has its leading role in decarbonisation and security of EU energy system due to the rapid ongoing deployment of variable renewable energy generation that will only reach its full potential with the deployment of additional energy storage. The future energy system will need more flexibility, stability and reliability to achieve the objectives of the European Green Deal and the REPowerEU initiatives.

Energy storage can play a crucial role in the current and future energy system. It can help decarbonise the economy and increase the efficiency and security of energy supply by providing flexibility, stability and reliability. Energy storage can also lower electricity prices during peak times, reduce price fluctuations and empower consumers to adapt their energy consumption to prices and their needs. The diversity of energy-storage technologies makes them suitable for many applications. And it is important to fully exploit the added value they can bring to the energy system and its users, together with other flexibility tools and energy-efficiency measures, while taking into account their environmental impact.

Energy storage provides flexibility when the share of variable renewable generation in the electricity system is above 74% of total installed capacity. Substantial investment therefore needs to be directed to energy storage, including heat storage and long-duration energy-storage technologies, to ensure a cost-effective, deep, and secure decarbonisation of the energy system. Debt financing has an important role to play in this investment. Furthermore, energy storage technologies can be an important element in interlinking electricity to other forms of energy, e.g. through hydrogen and power-to-x technologies [2].

The great diversity of energy-storage technologies makes them suitable for many applications, including: generation-support services; grid-support services; ancillary services; and energy-management services for consumers.

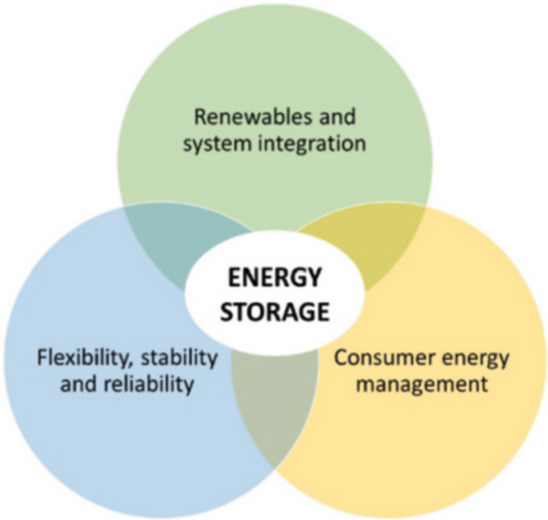

Fig.2. The contribution of energy storage to decarbonisation and security of supply [2]
Rys.2. Wkład magazynów energii do dekarbonizacji i bezpieczeństwa dostaw [2]

Process of storing energy can be divided into three phases:
- absorbing electricity from the electricity grid or from a directly connected power generator;
- storing that electricity in the form of electricity or any other energy carrier;
- reconverting the stored energy into electricity (power-to-x-to-power) or using the stored energy as another energy carrier itself (power-to-x).

It is important to fully exploit the significant added value that energy-storage technologies can bring to the energy system and its users. The numbered paragraphs below briefly detail the eight main services provided by energy storage.

1) Energy storage supports the integration of renewables (including thermal energy) into the system by: managing variable renewable-generation output, maximising renewable generation depending on grid and market circumstances; and increasing the capacity of congested grids so that new renewable-generation facilities can be deployed.
2) Energy storage facilitates the „electrification" of the economy and the decarbonisation of other economic sectors by buffering renewable energy in electricity or other energy carriers, like heat or hydrogen. This also facilitates the electrification of isolated areas.
3) Energy storage reduces price fluctuations and electricity prices during peak times and by providing peak capacity and by „shifting" energy from periods of low prices (or energy surplus) to periods of high prices (or energy deficits), thus smoothing out fluctuations and peak demand in renewable generation.
4) Energy storage provides flexibility and stability to the electricity system as a low-emissions alternative technology to fossil-fuelled power plants providing peak capacity, balancing, and non-frequency ancillary services.
5) Energy storage increases the resilience and reliability of the energy system by providing restoration capabilities if there is a loss of primary power supply in the electricity system and by serving as an alternative, low-carbon back-up solution if there are interruptions to the supply of energy.
6) Energy storage reduces congestion and grid-investment costs, particularly in areas with favourable renewable-generation potential. It does this by providing network-congestion-relief services in congested grid areas to absorb locally produced renewable electricity. This avoids, defers, or reduces the need for new construction or for upgrades of transmission and distribution networks.
7) Energy storage facilitates the integration of charging points for electric vehicles into the electricity system by reducing investments in upgrades to the local grid infrastructure and reducing costs related to peak-energy consumption during fast charging.
8) Energy storage empowers consumers by maximising „self-consumption" of local renewable energy (i.e. consumers using the energy that they themselves have produced) and increasing energy efficiency. This reduces consumers' energy bills (both the fixed and variable components of these bills) and increases their participation in electricity markets as active consumers, including through energy communities [2].

3. System components

3.1. Storage technology overview for District Heating purposes

3.1.1. Battery electricity storage

Battery electricity storage is a key technology in the world's transition to a sustainable energy system. Battery systems can support a wide range of services needed for the transition, from providing frequency response, reserve capacity, black-start capability and other grid services, to storing power in electric vehicles, upgrading mini-grids and supporting "self-consumption" of rooftop solar power. In the longer-term, batteries could support very high levels of varia-

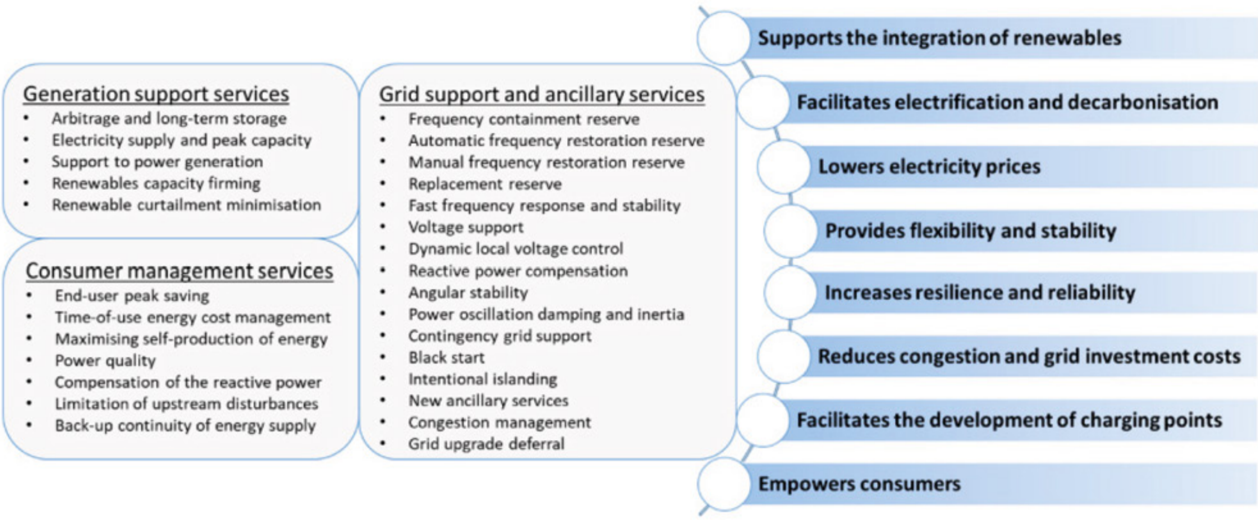

Fig.3. Energy-storage application and added value [2]
Rys.3. Zastosowanie i wartość dodana magazynów energii [2]

Fig.4. Battery electricity storage Pillswood in Cottingham in UK – Europe's largest battery energy storage system (BESS), MWh [5]

Rys.4. Bateryjny magazyn energii Pillswood w Cottingham w Zjednoczonym Królestwie – Największy europejski bateryjny magazyn energii (BME), MWh [5]

ble renewable electricity, specifically by storing surplus energy and releasing it later, when the sun is not shining or the wind not blowing strongly enough.

Battery electricity storage systems offer enormous deployment and cost-reduction potential, according to the IRENA study entitled "Electricity storage and renewables": Costs and markets to 2030. Total installed costs could fall between 50% and 60% (and battery cell costs by even more perhaps), driven by optimization of manufacturing facilities, combined with better combinations and reduced use of materials up to 2030. Battery lifetimes and performance will also keep improving, helping to reduce the cost of services delivered. Lithium-ion battery costs for stationary applications could fall to below USD 200 per kilowatt-hour to 2030 for installed systems [9].

The Pillswood battery electricity storage has 98 MW installed power with the capacity of 196MWh that means it can supply electricity to 300.000 households for two hours. The storage was made in Li-Ion technology. It consist of 78 modules.

BESS in UK bring at least five benefits:

- Helping the UK to meet its target of Net Zero to 2050
- Enabling clean energy generation – with no greenhouse gas emissions or air pollution
- Helping to secure the UK's energy supply
- Achieving biodiversity gains thanks to landscaping, including planting trees and over 1km of hedgerows
- Zero cost to the tax payer because the site has been built without subsidy

Battery storage assets participate in four key markets in UK:

- Capacity Market
- Wholesale Market
- Balancing Mechanism
- Ancillary Services

3.1.2. Heat storage

Thermal energy storage (TES) can help to integrate high shares of renewable energy in power generation, industry, and buildings sectors. TES technologies include molten-salt storage and solid-state and liquid air variants.

TES technologies offer unique benefits, such as helping to decouple heating and cooling demand from immediate power generation and supply availability. The resulting flexibility allows far greater reliance on solar and wind power and helps to balance seasonal demand. TES supports the shift to a predominantly renewable-based energy system and reduces the need for costly grid reinforcements.

The global market for TES could triple in size by 2030, growing from gigawatt-hours (GWh) of installed capacity in 2019 to over 800 GWh by 2030. Investments in TES applications for cooling and power could reach between USD 13 billion and USD 28 billion in the same period. Investments to drive technological development and measures to enhance market pull, combined with a holistic energy policy aimed at scaling up renewables and decarbonizing energy use, can unlock rapid growth in TES deployment.

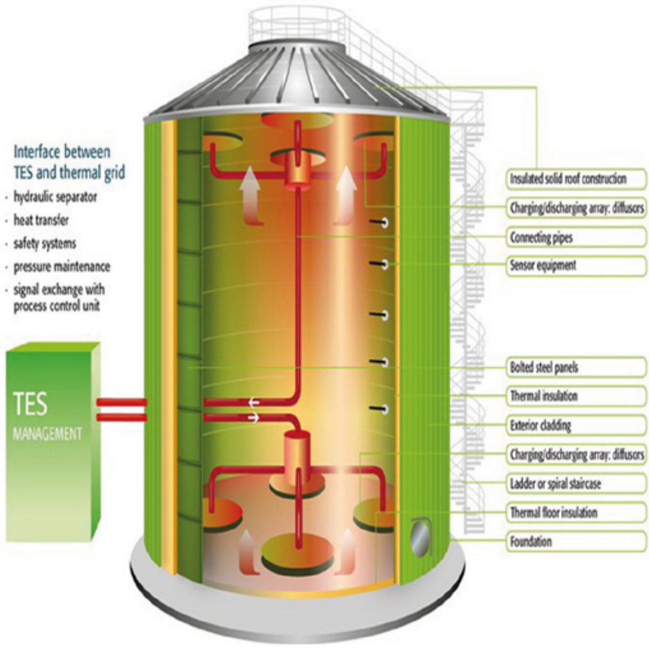

Fig.5. Tank Heat Storage [1]

Rys.5. Zbiornikowy magazyn ciepła [1]

3.2. Heat boilers

3.2.1. General overviews

Electric boilers are devices in the MW size range using electricity for the production of hot water or steam for industrial or district heating purposes. They are usually installed as peak load units in the same way as an oil or gas boilers. Hence, the following description of electric boilers is based on an operation strategy, aiming at approx. 500 full-load hours/year.

The conversion from electricity to heat takes place at almost 100% efficiency. However, from an exergetical point of view, this technology should be justified by its systemic advantages. Electric water heaters can be a part of the energy system facilitating utilization of wind energy and enabling efficient utilization of various heat energy sources.

Thus, the application of electric boilers in district heating systems is primarily driven by the demand for ancillary services rather than the demand for heat. Although, examples of electric boilers, that operate on the spot market can be found.

Generally, two types of electric boilers are available:

- Heating elements using electrical resistance (same principle as a hot water heater in a normal household). Typically, electrical resistance is used in smaller applications up to 1-2 MW. These electric boilers are connected at low voltage (e.g. 400 or 690 V, depending on the voltage level at the on-site distribution board).
- Heating elements using electrode boilers. Electrode systems are used for larger applications. Electrode boilers (larger than a few MW) are directly connected to the medium to high voltage grid at 10-15 kV (depending on the voltage in the locally available distribution grid) [12].

The electrode boiler, an electrically operated boiler in which the water to be heated is itself used as the electrical resistance, provides a reliable and robust way of converting power to heat, capable of making direct use of voltages up to about 24kV without step-down transformers and of achieving very high ramp rates (helped by the absence of heating surfaces and boiler pipework). The technology has been around for some years but has attracted renewed interest as a means of helping to maintain stability in grids with a high percentage of renewables, and as a cost effective power-to-heat option (Fig.6, Fig.7)[11].

The water in electrode boilers is heated by means of an electrode system consisting of (typically) three-phase electrodes, a neutral electrode and a water level & flow control system. When power is fed to the electrodes, the current from the phase electrodes flows directly through the water in the upper chamber, which is heated in the process. The heat production can be varied by varying the flow through the upper chamber and the power that is led through, thus enabling output to be controlled between 0 and 100 % [12].

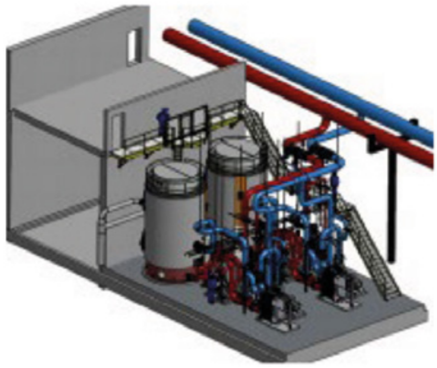

Fig.7. Illustration of 2x40 MW electric boilers installed at Studstrup power plant in Denmark. The heat exchangers in front of the electric boilers transfer the heat from the water circuit in the boiler to the district heating circuit (blue/red piping) [12]

Rys.7. Ilustracja kotłów elektrodowych 2x40MW zainstalowanych w elektrociepłowni w Studstrup

In a similar technology, the heat output is varied, by varying the contact area between water and electrodes, by covering the electrodes in control screens. Thus the contact area between water and electrodes can be varied by varying the water level around the electrodes.

In both technologies, there will be no high-voltage consumption in a stand-by situation, as the only stand-by consumption is due to circulation pumps, which lies in the range of 5 % of full load.

3.2.2. Regulation ability

Electric boilers can participate in up – and downward regulation. Modern electrode boilers have a minimal standby consumption when used as frequency-controlled reserves (down regulation). The standby consumption varies with the type of electric boiler. New electrode boilers of e.g. 12 MW have electricity consumption down to a few kW and no consumption at high voltage. Older types may have a standby consumption of 5-10 %. The above mentioned new generation of electrode boilers operate in such a way that the voltage is kept in the boiler, without applying any power. Using this technology, the only

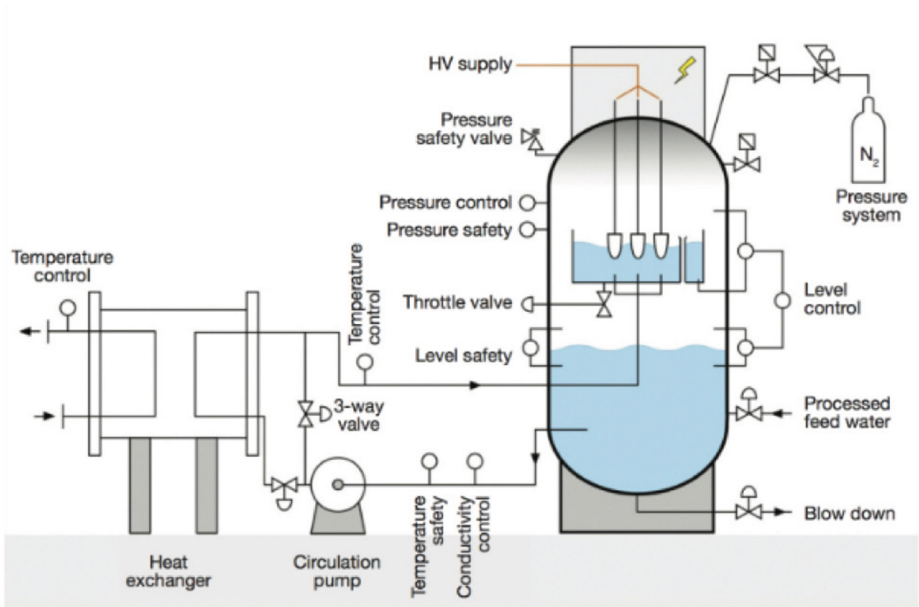

Fig.6. Schematic illustration of an electrode boiler. The heat is generated in the upper chamber through ohmic resistance between the electrodes. The boiler is pressurized with an inert gas system, e.g. nitrogen[11]

Rys. 6.Schemat kotła elektrodowego. Ciepło jest generowane w górnej komorze poprzez rezystancję omową pomiędzy elektrodami. Kocioł jest pod ciśnieniem inertnego gazu, np. azotu [11]

„stand-by consumption" is related to internal pumps and electric boilers can start with close to no standby consumption. Considering the close to none standby demand, many plants chose to keep the boiler operating in stand-by mode in order to be able to utilize the electrode boilers immediately when necessary.

Alternatively, it is possible to offer regulating power from cold start, hence eliminating the need for a standby consumption. This is made possible ramp up times of approx. 5 minutes in cold start situations, typically being shorter than necessary to participate on e.g. the power balancing market. However, due to the above-mentioned minimal standby consumption, operation on electrode boilers in standby is very common. The load shift from 0-100 % of nominal capacity is approx. 30 seconds [12].

3.2.3.Advantages and disadvantages

Advantages

Due to its very simple design, the electric boiler is extremely dependable and easy to maintain. The boiler has no built-in complex components, which may impede operation and maintenance. The boiler has quick start-up and fast load-response. It requires no fuel feeding systems and no stack.

Disadvantages

As the input energy is electricity, the operating costs are subject to the variation in the electricity prices (market dependent) and the taxes on electricity. Electricity prices thus constitute a major part of the operation costs, without being the only factor to consider when evaluating the economy of operation.

In case electric boilers utilize power from heat, exergetical losses will have to be considered in the evaluation of the total energy balance. Depending on the type of grid connection (full/limited), the availability of the electric boiler may be limited.

3.2.4.Environment

During operation, the electric boiler uses electricity and the environmental impact from operation depends on the origin of the electricity. Apart from the emissions, due to the consumed electricity, electric boilers have no local environmental impact [12].

In an electrode boiler AC current flows in water between three or more electrodes. The electrical resistance of the water generates the heat directly. The heat can be used to provide hot water for a heating system or to produce steam for industrial processes.

The electrode boiler consists of an outer and an inner container. The electrodes are suspended inside the inner container, which is electrically insulated from the outer shell.

The water and the inner container forms an insulated zero point in the star connection between the electrodes.

A circulation pump brings water to the electrode container. The output of the boiler is proportional to the water level at the electrodes.

A traditional fired boiler needs a combustion chamber and a tube section to transfer heat from the flame to the water. This results in large, heavy and costly construction. In the electrode boiler heat is generated directly in the compact water volume between the electrodes.

The electrode boiler uses medium voltage, in the range 6-24 kV. Unlike a typical low voltage heater, it doesn't need a low voltage transformer, so the costs associated with the transformer, cabling and low-voltage switchgear are avoided.

The technology of the electrode boiler is well established and well understood, benefitting from many years of experience.

The capacity range of electrode boiler is around 5-60 MW [12].

4. Polish wholesale market

The volume of gross domestic electricity generation in 2021 was at a higher level compared to the previous year, and amounted to 173,583 GWh (an increase of 14 % compared to 2020). In the same period, gross domestic electricity consumption amounted to 174,402 GWh and increased by 5.4% compared to 2020. The growth rate of domestic electricity consumption was lower than the GDP growth rate in 2021, which according to preliminary estimates of Statistics Poland (GUS) amounted to 5.7%.

The structure of electricity production in 2021 did change insensibly compared to 2020(see Table 1). The vast majority of generation is still based on conventional fuels, i.e. hard coal and lignite. The production in RES has increased which is the outcome of the growth of installed power by 5 GWh year-to-year.

In 2021, the share of imports in the domestic balance of physical flows constituted 8.0 % of total electricity fed into the grid, while the share of exports constituted 7.6 % of electricity off-taken. As compared to 2020, share of imports declined by 3.8 percentage point, while share of exports increased by 3.4 percentage point.

In 2021, installed capacity in national electricity system amounted to 53,656 MW, and generating capacity totalled 54,382 MW, which is an increase by 9.0 % and by 10.8 %, respectively, as compared to 2020. An average annual capacity demand was 23,673.00 MW, against maximum demand of 27,617.20 MW, which is an increase by 5.6 % and 3.1 % respectively, as compared to 2020 (see Table 2). The ratio of available capacity to generating capacity in 2021 was 57.6 % (decrease by 4.1 percentage points as compared to 2020).

Table 1. Structure of electricity generation, domestic balance of physical flows in cross-border exchange, and electricity consumption in 2020-2021, [GWh] [17]

Tabela 1. Struktura wytwarzania energii elektrycznej, krajowy bilans fizycznych przepływów wymiany między granicznej oraz zużycie energii elektrycznej w latach 2020-2021, [GWh] [17]

	2020	2021	Dynamics (2021/2020; 2020=100)
Total electricity production	**152,308**	**173,583**	**113.97**
including: hard coal-based power plants	71,546	93,037	**130.04**
lignite-based power plants	37,969	45,367	**119.48**
gas-based power plants	13,924	13,366	**95.99**
industrial power plants	9,799	-	
water-based utility power plants	2,698	2,830	**104.89**
wind sources	14,174	14,234	**100.42**
other RES	2,198	4,749	**216.06**
cross-border exchange balance	13,224	820	**6.20**
Domestic electricity consumption	**165,532**	**174,402**	**105.36**

Table 2. Installed capacity of domestic power plants (at the end of the year) [17]

Tabela 2. Moc zainstalowana w krajowych elektrowniach (na koniec roku) [17]

	Installed capacity [MW]		
	2020	2021	dynamics (year/year)
Installed capacity of domestic power plants:	49,238	53,656	**8.97%**
In utility power plants:	36,364	38,570	**6.07%**
In hydroelectric utility power plants:	2,356	2,380	**1.02%**
In thermal utility power plants:	34,008	36,190	**6.42%**
Hard coal based:	22,747	24,611	**8.19%**
Lignite based:	8,478	8,262	**-2.55%**
Gas-fired:	2,782	3,317	**19.23%**
In wind sources and other RES:	10,229	15,086	47.48%
In industrial power plants:	2,645	0	-100.00%
Installed capacity in centrally-dispatched generation units	29,429	27,850	-5.37%
Installed capacity in not centrally-dispatched generation units:	19,810	25,806	30.27%

The demand curves shown on Fig. 8 present that the maximum power demand is peaking around noon and keep that level until 6:00 – 7:00 p.m. It has further impact on shaping the electricity prices (Fig.9).

We can be observe that all the curves have similar shapes, the only difference is the level of prices. High electricity prices appear in similar parts of the day, independently of the day of the week. The highest are at 8:00 pm and the lowest at 4:00 am. The highest daily

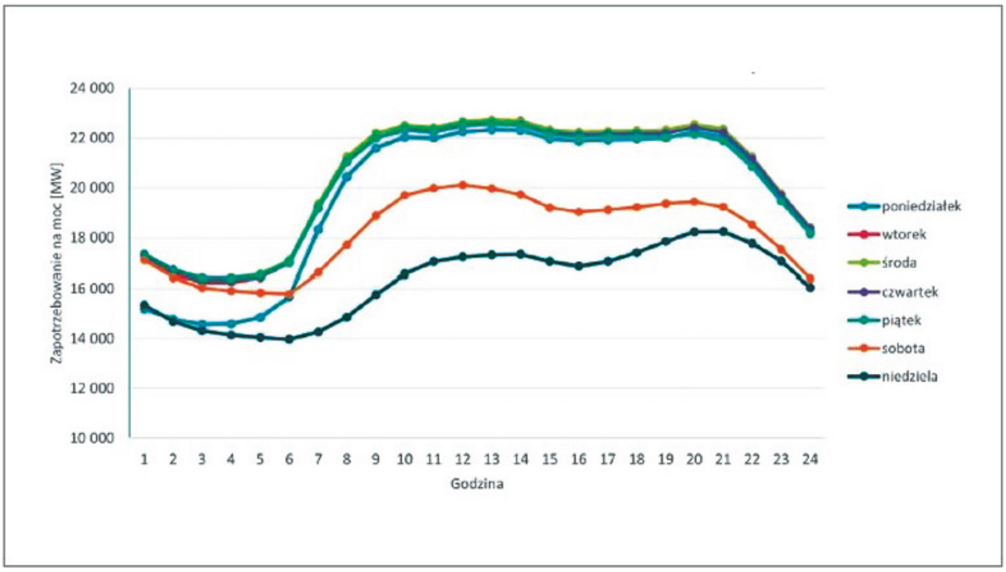

Fig.8. Polish power demand daily curves in one whole week in 2022 [14]

Rys.8. Dobowe krzywe zapotrzebowania w Polsce w jednym tygodniu 2022 roku [14]

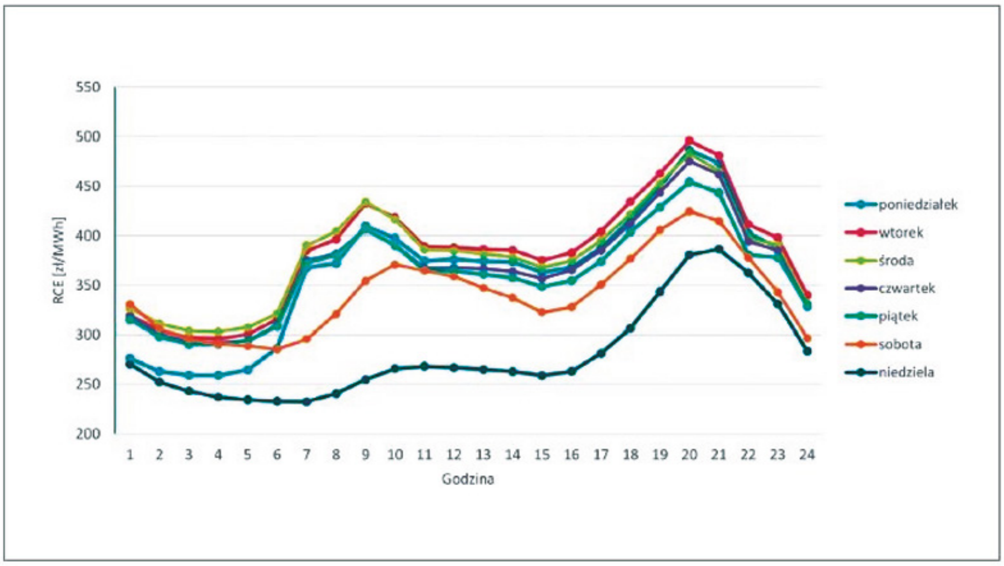

Fig.8. Polish power demand daily curves in one whole week in 2022 [14]

Rys.8. Dobowe krzywe zapotrzebowania w Polsce w jednym tygodniu 2022 roku [14] mean Energy price occur in weekdays, on Saturdays the price is significantly lower and the lowest prices are on Sundays. In the first few hours of Mondays the prices are lower than on other weekdays, which is caused by the previous day Sunday (the day off), later the price is reaching the average of other days of the weekdays.

The correlation can be observed between daily power demand and market energy prices. In comparison the electricity price and daily power demand is the lowest on Sunday. Additional similarities are low electricity prices during night hours and its rapid increase after 6:00 a.m. [14].

5. Heat market

The Polish heat market faces a huge challenge of a transition process forced primarily by the climate policy, including stricter environmental requirements and the rising cost of CO_2 emission allowances. Without transformation and addressing challenges, specifically as regards measures to reduce greenhouse gas emissions as well as the modernisation and modification of heat generation methods, the branch will experience permanent increases in heat prices resulting in a market erosion that means shrinking share of district heating in the supply of heat to final consumers.

The heat sector in Poland was affected by the pandemic in 2021 as well as the symptoms of destabilisation in the market for fuels imported from the east in the second half of the year. The year 2021 saw a dramatic increase in the cost of CO_2 emission allowances, which, together with the increase in fuel prices, was reflected in the increase in the average price of heat sold to consumers.

In 2021, for the first time in many years, district heating operators had to struggle with major destabilisation in the fuel supply market, which affected in particular gaseous fuels, the bulk of which was imported from the east. The increase of the cost per unit of natural gas was remarkable – in case of high-methane natural gas (GZ-50) the unit cost doubled while the price of low-methane natural gas increased by 78 percent. On the other hand, the unit costs of coal, lignite and heavy fuel oil used in heat generation went down. These factors influenced the price of heat which is closely linked to the type of fuel used in generation and the cost of CO_2 emission allowances, which soared during last year(see Fig.10, Fig.11) [18].

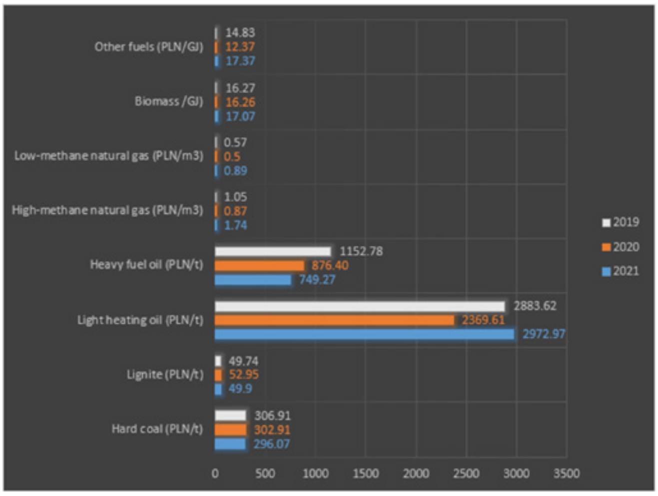

Fig.10. Unit cost of fuels consumed in heat generation sources in 2019-2021 [18]

Rys.10. Jednostkowe koszty paliwa w źródłach wytwórczych w latach 2019-2021 [18]

The rise in fuel prices and the cost of carbon emission allowances observed in 2021 impacted the level of tariff prices and charges approved by the President of Energy Regulatory Office (URE) for heat generated from non-CHP sources only by the end of the year (see Fig.12,Fig.13).

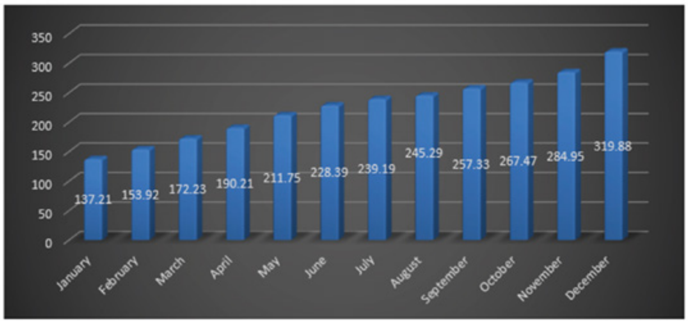

Fig.11. Average price of CO_2 emission allowances in 2021 calculated based on 30 quotations (PLN/tCO2) [18]

Rys.11. Średnia cena uprawnień do emisji CO_2 w 2021 roku skalkulowana na bazie 30 notowań (PLN/tCO2) [18]

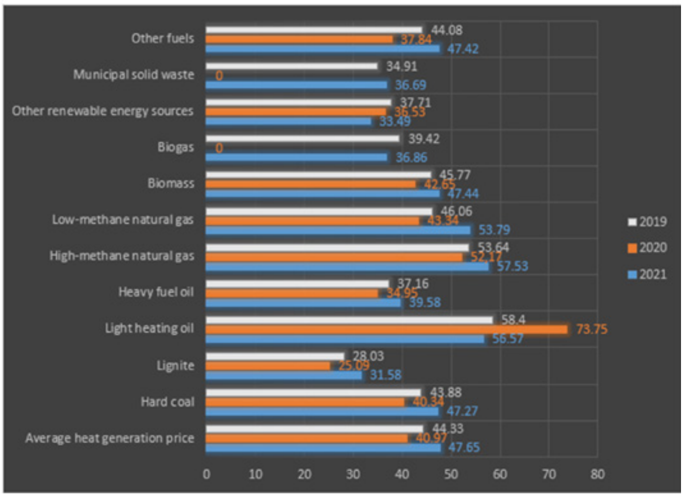

Fig.12. Prices for heat generated from different types of fuel in 2019-2021 (PLN/GJ) [18]

Rys.12. Ceny ciepła wytworzone z różnych rodzajów paliw w 2019-2021 [18]

We can observe the heat demand varies depending on the household type but the average that is presented by the red curve shows that there are two peaks during morning hours and evening hours. This is caused by the inhabitants activity.

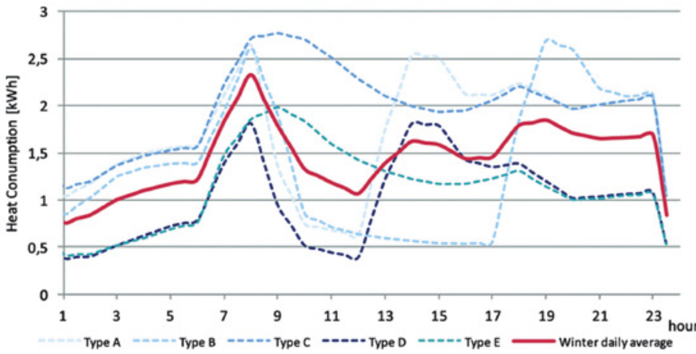

Fig.13. Daily heat demand for different households types for a winter day. [14]

Rys.13. Dzienne zapotrzebowanie w różnych typach mieszkań w zimie. [14]

The demand for the heat water is peaking between 6-8 a.m. and 7-21 p.m. according to IEO research within the research project ComBioTES(see Fig.14)[6]. The diagram in Fig.14. presents demand for heat water for four-person family.

6. Discussion

Stabilization of the heat load of the production sources is the „eternal" problem of district heating. Optimization of the production

Fig.14. Hourly electricity consumption for hot water preparation [6]

Rys.14. Godzinowe zużycie energii na potrzeby przygotowania ciepłej wody użytkowej [6]

units utilization and keeping them running at the best of their performance is the aim for heat producers. The performance influence the production cost is presented. The peaks in morning hours both for central heating and hot water, in particular during winter period are presented (see Fig.13, Fig.14). The solution for smoothing the production in order to meet demand is to use storage system together with electrode boilers. The proposal for storages is both in electricity and heat to gain more flexibility and better response to the wholesale energy market. As it is presented in Fig.9. the electricity prices follow the heat demand curve (see Fig.13), so during the peak hours in the heat business as usual case the HOB's would go into the operation supplied by fossil fuel or electrode boilers powered by electricity in the peak hours.

The EU energy strategy and policies points out that power sector as well as heating sector need to be decarbonised by 2050, the electrode boilers will be more and more popular and its exploitation will have the impact on the electricity network load and this leads to high electricity prices during peak demand in winter season, hence the heat prices for final customers.

Another issue is that the electrode boilers themselves are zero emission and if they are supplied with the RES power should produce ,,green" heat. According to UE policies green energy cannot be counted twice, so they will remain zero emission units for the moment being. Postulate of the heating branch would be to count the heat produced out of green sources as renewable heat.

The combination of heat and electricity storages and electrode boiler and RES energy utilization come along with the forecast of RES development in Poland that can be found Energy Policy for Poland where RES production share increases from 22% in 2020 to 40% in 2040(see Fig.15).

The storage systems are supported by EU regulations to ensure a table and flexible electricity supply and for district heating possibility to store electricity when there is over production of RES in the electricity network and the prices of electricity are relatively low. Moreover to ensure the optimal operation of electrode boilers and secure the heat supply to district heating network the heat storage would be complementary part to proposed new system. The electrode boiler and storages can also offer ancillary services for DNOs like demand side response.

Conclusions

The novel approach for district heating in terms of climate challenges and changing regulation environment to follow holding of global warming maximum at 2° is presented in this paper. It fits in the EU regulations regarding the role of storage and district heating system as well as more and more RES in the feed of distribution and transmission networks. The EU and Polish scenarios assume significant increase of RES, thus the storage and consumption of excess electricity from the distribution network is needed as well as reduction of electricity consumption when a shortage of electricity availability in the network is and the heat needs to be supplied to the district heating network for the consumers. The changes to existing policies should be implemented, in particular for the heat part, like renewable heat issues, ancillary services for electricity storages that are not directly connected to the individual electricity connection point to the grid, thus cannot bring income from TSO. Further development and techno-economic validation to confirm its economic feasibility is needed for the proposed system. By the way, it is worth noting that however, the cheapest energy is that which is saved.

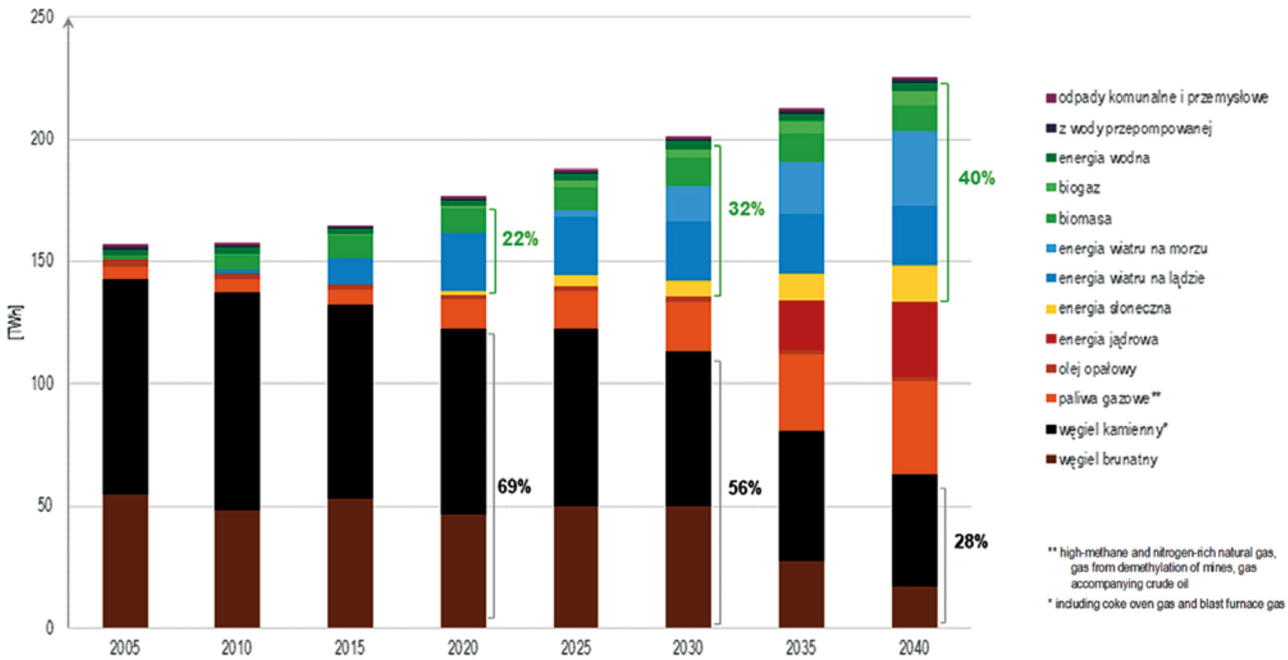

Fig.15. Gross electricity generation forecast by fuel (TWh) [10]

Rys.15. Prognoza produkcji energii elektrycznej brutto według paliwa (TWh) [10]

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