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Renewable Energy Sources in Heating

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Foreword

This report is a continuation of Forum Energii's work on the concept of clean heat development in Poland. We want to look at the heating sector in a broad way, not only as heating systems but above all as individual heating sources that generate as much as 75% of the heat consumed by households in Poland. This sector is the main source of air pollution.

So far, we have developed the Clean Heat 2030 strategy, identified problems with small heating and district heating systems, prepared a strategy to eliminate smog in Żywiec, and compared the best Danish and German experiences. In 2019, we presented four scenarios for improving air quality and reducing CO_2 emissions in the Clean Heat 2030 strategy. However, the environment is changing rapidly. Currently, the whole of Europe is discussing climate neutrality in 2050. Therefore, in this analysis we are focusing on key technologies to achieve our strategy's most ambitious scenario, which assumes full decarbonisation by 2050.

The technologies we propose may be controversial. There are no ideal solutions that will satisfy everyone. The availability of resources, costs, or production of components outside Poland may raise doubts. However, the choice must be made because the era of coal is coming to an end and Poles deserve clean heat. The age, technical condition, and efficiency of heating facilities leave much to be desired.

In this analysis, together with the Institute for Renewable Energy, we point out the technologies that we believe are worth focusing on in the next decade. We believe that Poland, moving away from coal, should make a leap towards renewable sources because only they guarantee energy independence in the long term, moderate costs, clean air, and reduction of CO_2 emissions. The development of RES in the heating sector should be accompanied by an ambitious industrial policy to create as many jobs as possible in this sector. Clean heat may become a flywheel for the Polish economy, which after the coronavirus crisis will need new development impulses.

We hope that our study will become a valuable inspiration for action.

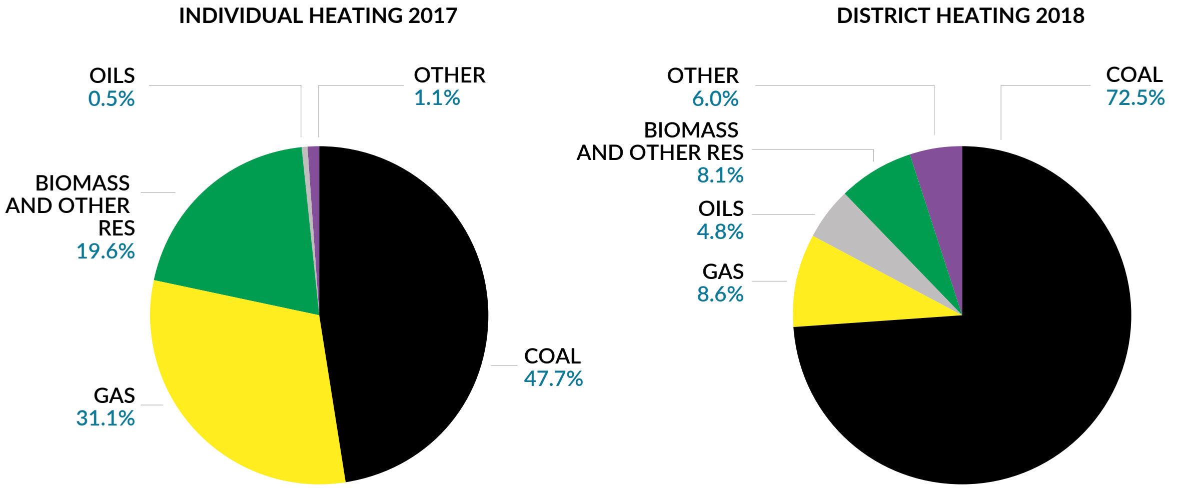
Enjoy your reading.
Joanna Maćkowiak-Pandera, PhD
President of Forum Energii

1. Introduction

Heating is defined here as district heating (DH) networks and the generation of heat at the household level that are responsible for as much as half of Poland's entire consumption.[1] The Polish heating sector is hugely dependent on coal (Figure 1), whose consumption for heating purposes is 24 million tonnes, of which 12 million tonnes are used in households.[2] This directly translates into air pollution and smog. A detailed diagnosis of heating in Poland is presented by Forum Energii in its report *Clean Heat 2030*.

The energy mix has hardly changed in recent years. The share of renewable energy sources rose from 11.7% in 2010 to only 14.56% in 2018, including the heat used in industry.[3] Such slow change will not reduce CO_2 emissions or improve air quality. This particularly slow pace of growth is seen in DH systems in which the share of RES in the fuel mix grew from 2.9% in 2002 to only 8.2% in 2018.[4]

Figure 1. Consumption of fuels for heating



Source: *Heating in Poland. Edition 2019*, Forum Energii, Warsaw 2019.

Heating[5] is defined here in broad terms, both as district heating which includes district-heating networks together with generation sources, as well as individual heating systems in households.

By disfavouring RES, Poland will be unable to meet the 2020 target of 17.05% for heating and cooling.[6] Further, it will be unable to meet the target for the next decade, which is 28.4%, as provided for in the most recent National Energy and Climate Plan for the Years 2021–2030.[7] And let's note here that this is achievable. This report shows that aspirations for district and non-district heating can be bigger. With proper effort, 40% of heat can come from RES already in 2030.

1 *Heating in Poland. Edition 2019*, Forum Energii, Warsaw 2019.
2 As a result, Polish households use 87% of the coal burnt by households in all EU countries.
3 Based on Eurostat data.
4 *Energetyka cieplna w liczbach–2018*, Urząd Regulacji Energetyki, Warsaw 2019.
5 Unlike Eurostat data for the "Heating and Cooling" sector, in the approach adopted here, industrial uses of heat are excluded.
6 *Krajowy plan działania w zakresie energii ze źródeł odnawialnych 2010–2020 [National Renewable Energy Action Plan (NREAP) for Poland]*, Ministry of the Economy, Warsaw 2010.
7 *National Energy and Climate Plan for the Years 2021–2030*, version of 18/12/2019, Ministry of State Assets, Warsaw 2019.

Why 40%

The pace of the discussion on climate neutrality of the European Union by 2050 is quickening, and the European Green Deal, a flagship initiative of the European Commission, provides incentives for ambitious action. That is why it is important to establish a long-term decarbonisation target in Poland's heating sector. To completely eliminate emissions by 2050, the share of RES by 2030 should be at 40%, per the decarbonisation scenario identified in the Clean Heat 2030 strategy. Such an approach will allow Poland to achieve a number of national economic and social goals (Table 1).

Table 1. Targets for district heating and individual heating by 2030 and 2050

Target/Area	2030	2050
1. Climate	CO_2 emission reduction (from 2016) by **42%**	CO_2 emission reduction (from 2016) by **100%**
2. RES	RES share of Heating & Cooling consumption at **40%**	RES share of Heating & Cooling consumption at **100%**
3. Energy efficiency	Reduction of the consumption of final energy by buildings by **21%** (from 2016)	Reduction of the consumption of final energy by buildings by **55%** (from 2016)
4. Environment and energy security	Replacing coal with other primary energy sources in buildings heated individually (and in DH by 2035)	Decarbonisation of heating systems – electrification of heating and use of RES and waste energy
5. District heating systems	Transformation of all heating systems into efficient systems	–

Source: *Scenario IV.* Decarbonisation of heating, in: *Clean Heat 2030. Strategy for heating*, Forum Energii, Warsaw 2019.

What are we proposing?

This report presents the path to achieve the 40% RES share in heating by 2030, inspired by the so-called decarbonisation scenario identified in the Clean Heat 2030 strategy. We are left with only 10 years to achieve that target. So, there is little time left for action, and we should act now. That is why RES development in heating will be based in the nearest decade largely on technologies already known and used in Europe. Most of them are not only commonly used but also manufactured by Polish businesses. In addition, it is important to note that the rise of new technologies to accelerate decarbonisation of heating is very likely; however, they will only supplement, rather than provide the foundation for the strategy for the next decade.

Achieving such a target in heating involves two measures:

1. **Decrease the demand for heat**. Our forecasts assume that in 2030, demand for heat will fall by 21% to 622 PJ compared to 789 PJ in 2016. Energy efficiency is key. Universal thermomodernisation of buildings, assumed in this report,[8] is a crucial tool for that.
2. **Change of structure of demand for fuels and installed capacity**. Fossil fuel technologies will be replaced by RES. Total installed capacity of the former in the entire heating sector will fall from 139 GW_t in 2016[9] to 71 GW_t in 2030. At the same time, RES installed capacity (including waste heat and incineration of municipal waste) will grow from 33 GW_t to 72 GW_t. Given the rather small growth in recent years, the growth of RES capacity in the next decade should be about 4 GW_t per annum.

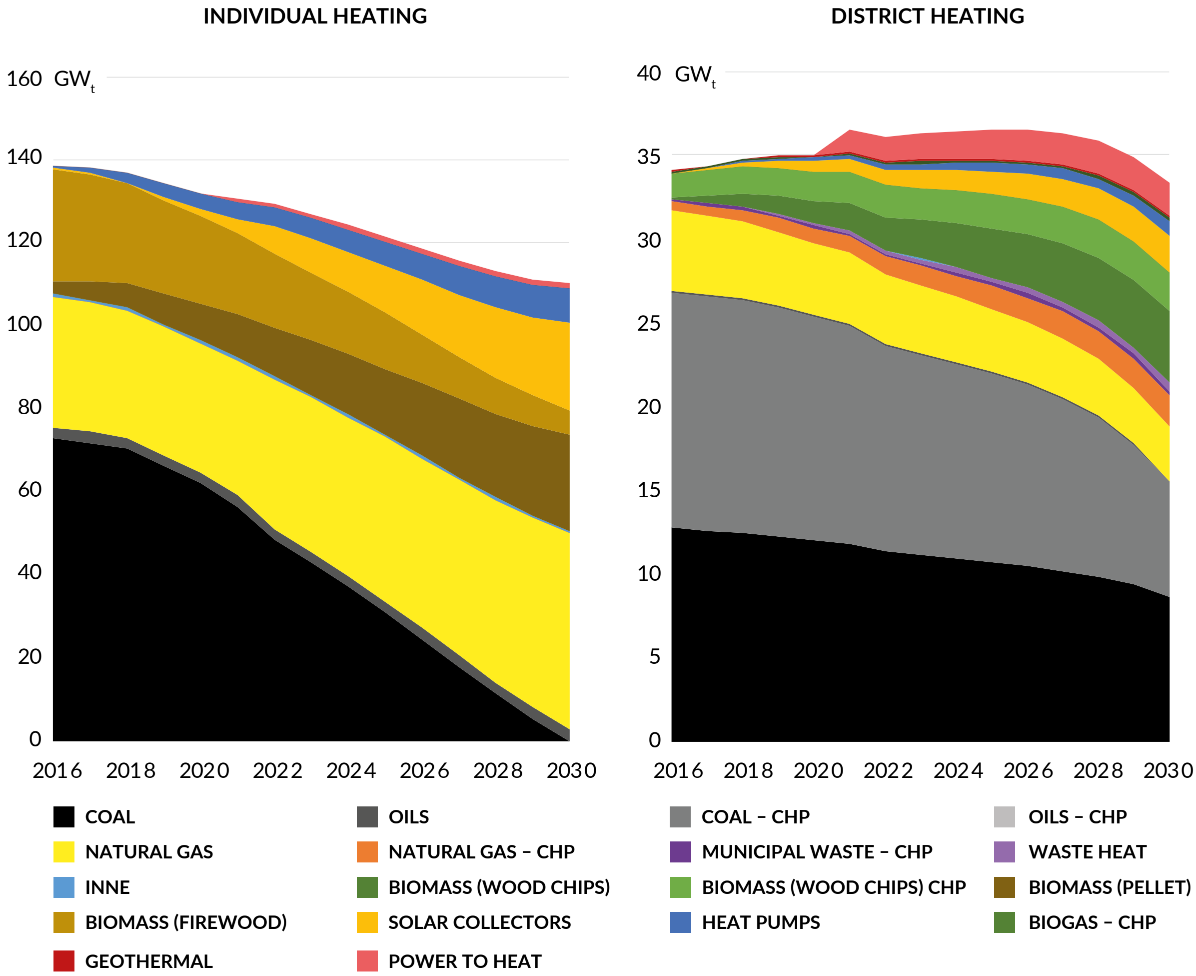
8 This is the thermomodernisation variant adopted in Forum Energii's report *Clean Heat 2030. Strategy for heating*. The share of buildings subject to thermomodernisation will grow to 75% in 2050. The scenario sees a significant growth of consumers connected to DH networks (DH consumers).

9 Based on *Clean Heat 2030*...

The delivery of both actions will affect both subsectors in the following way:

1. **Individual heating** – this analysis provides for the growth of RES in individual heating from 21% in 2016 to 40% in 2030. As a result, RES installed capacity will double from 31 GW_t to almost 60 GW_t, i.e., 54% of total power in individual heating versus 22% in 2016.
2. **District heating** – the share of RES in DH will grow from 9% in 2016 to 39% in 2030. The installed capacity will grow more than six-fold, from 2 GW_t to 12.2 GW_t, over the same period. It will translate into 37% of total capacity of DH versus 5% in 2016.

Figure 2. Structure of capacity used in individual heating and DH



Source: Developed by the Institute for Renewable Energy (IEO).

Table 2. Shares of thermal capacity in Poland's heating sector in 2016 and 2030

Capacity (MW_t)	2016	2030
Coal	99,691.9	15,442.1
Oils	2,785.6	2,807.4
Natural gas	36,642.1	52,421.3
Biomass	31,609.6	35,357.9
Biogas	56.0	233.4
Solar collectors	538.6	23,480.9
Heat pumps	248.5	9,147.7
Municipal waste	138.3	281.0
Waste heat	0.0	463.0
gP2H	0.0	3181.8
Other	693.7	618.5
TOTAL	172,404.4	143,435.2

Source: Developed by IEO based on *Clean heat 2030...*

2. Key figures

42%	Achievable CO_2 reduction level in heating sector by 2030
40%	Achievable share of renewable energy sources in heating sector in 2030
84 GW_t	Total capacity of coal-based plants that need decommissioning by 2030 (on 2016)
0 MW_t	Capacity of heating facilities using coal in households in 2030
72 GW_t	Postulated level of RES technology heating capacity in 2030
21%	Reduction of demand for heat between 2016 and 2030 due to building thermomodernisation projects
PLN 81.5 billion	Total investment spending for new RES technologies in the heating sector in 2020–2030
4 GW_t/year	RES installed capacity annual increase in 2020–2030 necessary to increase RES share in heating to 40% in 2030

3. Key conclusions

1. It is possible to increase the RES share in DH and individual heating to 40% by 2030. Important will be measures for energy efficiency and a change of structure of demand for fuels in this sector. The necessary preconditions include a broad thermomodernisation effort and discontinuing coal for heating purposes. These measures will reduce CO_2 emissions saved in the heating sector by 42%.

2. The greatest investment effort should be focused on three technologies whose heating capacity may significantly increase in the nearest decade:

   - heat pumps (to 9.1 GW_t),
   - solar collectors (to 23.5 GW_t)
   - pellet boilers in households (to 23 GW_t).

   What is important is that pellet boilers are considered a transitional technology in decarbonisation of individual heating by 2050. In addition, electric heating, biogas plants, heat storage technologies and geothermal modules will supplement the heating decarbonisation process.

3. Total installed capacity of RES technologies in the heating sector, including waste heat and municipal waste incineration, should grow from 33 GW_t in 2016 to 72 GW_t in 2030. Given the small growth in recent years, RES capacities in the next decade should be about 4 GW_t per annum. The output of fossil fuel systems should decrease from 139 GW_t in 2016[10] to 71 GW_t in 2030.

4. Investment spending on new RES systems in heating in 2020–2030 will approach PLN 81.5 billion. Average annual spending at about PLN 8 billion per year is an opportunity for technology providers but also a real challenge for investors and the financial sector. It is equivalent to almost 40% of total investment spending in Poland in 2017 for the production and distribution of electricity, gas, steam and hot water.[11]

5. The current trend of development of RES technologies in Poland is insufficient to achieve the 40% share of renewable energies in heating in 2030 or to achieve the target share of RES heat for the heating and cooling sector at 28.4% as defined in the National Energy and Climate Plan. Therefore, the current efforts should be accelerated.

6. National manufacturing capacity is insufficiently developed to achieve such an ambitious investment pace. Since RES development is too slow, Polish companies have not created the appropriate production base because they did not need to employ high numbers of workforce or manufacture large quantities of components. Therefore, the capacity of the national sector for the manufacture and installation of RES systems, including the R&D sector, need to be developed. However, this process will take time, from two to five years.

7. Relevant industrial policy must be supported by a coherent strategy for the heating sector. Such a strategy must enable the introduction of necessary regulation and elimination of unnecessary regulation and consider the starting point and development capacity of investors in the heating industry. A predictable development path in this sector will make the industry feel more secure and will increase the contribution of decarbonisation of the heating sector to Poland's economic growth.

10 Based on *Clean Heat 2030…*

11 Which is PLN 21 billion. *Biuletyn Statystyczny* 2019, no. 3.

4. Purpose of this report

This analysis is aimed at presenting key technologies that would enable Poland's heating sector to achieve a 40% RES share in 2030.[12] These technologies can be employed in both DH and individual heating.[13] Unlike other countries of the European Union, some of these technologies are not widely used in Poland.

5. Proposed technologies and combined investment cost

This report presents RES technologies key to the transition by 2030, and the potential for their development is analysed from various perspectives (Table 3).

Table 3. Conditions of RES technologies in heating

Technology	Conditions +++ Most favourable; ++ Moderately favourable; + Least favourable					
	Resources	Universal use	Costs	Availability of Polish manufacturers	Legal requirements	Main area of application
Solar collectors	+++[a]	+++	+++	+++	+++	Domestic hot water
Pellet boilers – individual heating	++[b]	+++	++	+++	+[c]	Heating
Biomass boilers – DH	++	++	++	+++	+[d]	Heating
Resistance heaters	+++	++	+++	++	++[e]	Domestic hot water
Electric boilers	+++	+	+	++	++[e]	Heating
Heat pumps	+++	+	++	+	++[e]	Heating
Biogas	++	+	+	+	+++	Heating
Heat storage facilities	+++	+	+	++	++	Heating
Geothermal	+	+	+	+	+++	Heating

Source: Developed by the authors.

a – unlimited resources;
b – rich, but limited resources;
c – many documents of regional air protection programmes consider pellets a solid fuel, and thus undesirable;
d – under the RED II Directive, large DH plants and Combined Heat and Power plants with a capacity of more than 20 MWt using solid biomass will be covered by more stringent criteria for sustainable development and reduction of greenhouse gas emissions;
e – no legislation to increase the profitability of electric power for heating purposes.

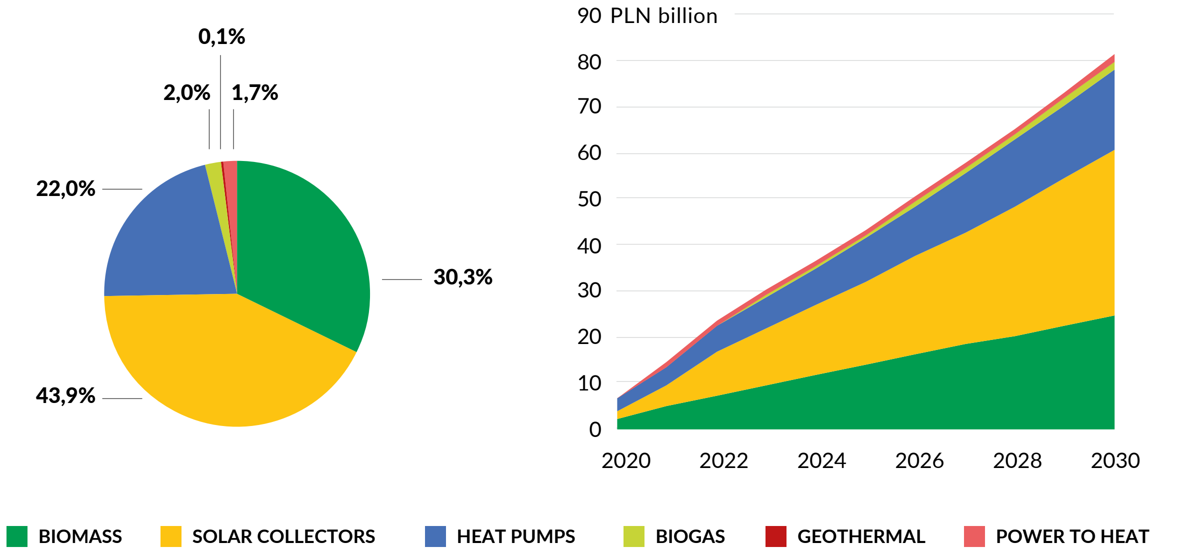
12 This was inspired by Scenario IV of the *Clean Heat 2030...* report. It assumes decarbonisation of the heating sector by 2050. For the purpose of this study, that scenario has been slightly updated (see Appendix).

13 The adopted approach did not analyse technologies used in the manufacturing and construction sectors, which play an important role in demand for specific technologies. For instance, processes with heat recovery technologies have not been considered. With time, such technologies will become a source of heat in municipal heating systems, in particular in industrial agglomerations, such as Warsaw, Katowice, and others.

Costs

Combined investment spending on new RES in heating in 2020–2030 will be PLN 81.5 billion. it is worthwhile to note that PLN 21 billion were spent in 2017 for investments in the production and supply of electricity, gas, steam, and hot water.[14] Therefore, a forecast of capital spending at about PLN 8 billion per year is not only an opportunity for technology providers but also a real challenge for investors and the financial sector.

Figure 3. Combined capital expenditures and structure of expenditures, by technology



Source: Developed by IEO.

The vast majority of capital expenditures (CAPEX) are for three RES technologies crucial for the heating sector: solar collectors, biomass boilers, and heat pumps. Unit costs of all technologies, presented by the Institute for Renewable Energy, are developed based on analyses and case studies.

The analysis of particular technologies in the following section consider, where possible:

- CAPEX – capital expenditure per unit;
- OPEX – operating expenditures per unit, usually for fuel and/or service;
- LCOH – Levelised Cost of Heat[15], which shows the average cost per heat unit spent throughout the lifecycle of the heat source. It includes capital expenditures and forecasted variable costs, including the cost of fuels.[16]

OPEX are important for the appliance user because, in many cases, capital expenditures may be reduced due to subsidies or other forms of public aid. As a result, the LCOH may be reduced, coming close to variable costs. Among the above-mentioned technologies, biomass, and to a significant extent also heat pumps, have relatively high operating costs (OPEX) for RES, mainly due to the cost of fuel for biomass, and for heat pumps, the cost of power. The simplest way for investors or heat consumers to become independent from the OPEX (cost of fuel, cost of environmental fees, and others) and the risk of these increasing is to elevate the role of sources not based on fuel burning processes.

14 Biuletyn Statystyczny 2019, no. 3.
15 This paper does not address a detailed LCOH analyses on specific examples and with specific assumptions.
16 The price of heat thus calculated is higher than that which we know from the current market practice, due to the forecast increase in variable costs.

6. Description of the proposed technologies

This section describes more broadly particular RES technologies key to the 2030 perspective, including their costs. In addition, we compare the pace of development of particular technologies necessary to achieve a 40% RES share in heating by 2030 with their average growth in several recent years in Poland. For the technologies not used in Poland yet (e.g., electric boilers in DH systems), the experience of the Danish DH system were adopted as the benchmark (technical trend). A compilation and complete catalogue of data and economic parameters, together with the list of key Polish suppliers, is in the Appendix.

6.1. Solar collectors

This technology is based on absorbing solar radiation and transforming it into thermal energy used for water heating. Traditional solar collectors are used for domestic hot water heating (60–70% per year) or as a support to central heating in decentralised systems with thermal input on the order of several kW_t. Larger systems, with power capacity of several dozens or even several hundreds of kilowatts, are built in, e.g., large housing cooperatives or hospitals. Solar collectors are simple, easy to use, with an accessible price, almost no-cost operation, and availability on the market.

Poland is a leading country in Europe and globally in the manufacture and application of solar collectors. It was fifth in the EU in 2017 in terms of sales and installation of solar water heating systems.[17]

Flat-plate collectors are most popular in Poland.[18] They are reliable, have a good energy-to-price ratio and are widely used in the European Union, and Polish manufacturers excel in making them—a total of several dozen companies. Some of them also manufacture hot water storage tanks, an important part of solar collector installations, which stores heat in daily and hourly cycles.[19] More than 80% of all solar collectors sold in 2015 in Poland were manufactured domestically.[20] Poland exports its products to many countries worldwide.[21]

However, evacuated tube collectors, and especially their key components—evacuated tubes—are largely imported, mainly from China, and then assembled into finished collectors by companies in Poland. Such collectors are more efficient in using solar energy, especially in the winter and transitional seasons. However, they are significantly more expensive and have a shorter lifetime.

Application

In Poland, a solar collector can work with central-heating boilers or heat pumps, as well as home photovoltaic systems. In particular, photovoltaic systems can supply power to circulation pumps, and water storage tanks for solar collectors can collect surplus electricity and store it as hot water for the period of lower demand for power. Meanwhile, a central heating boiler/heat pump can heat up water in the storage tank when solar collectors do not deliver sufficient power, e.g., on cloudy days.

In addition to private homes, most solar collectors manufactured in Poland also can be used in middle-sized (e.g., in housing cooperatives) and large DH systems. According to the EU classification, large solar collector systems have a surface area of 500 to 50,000 m^2 (0.35–35 MW_t).[22] Currently, the largest solar collector fields are operational in the DH systems of Olsztyn and Iłża.

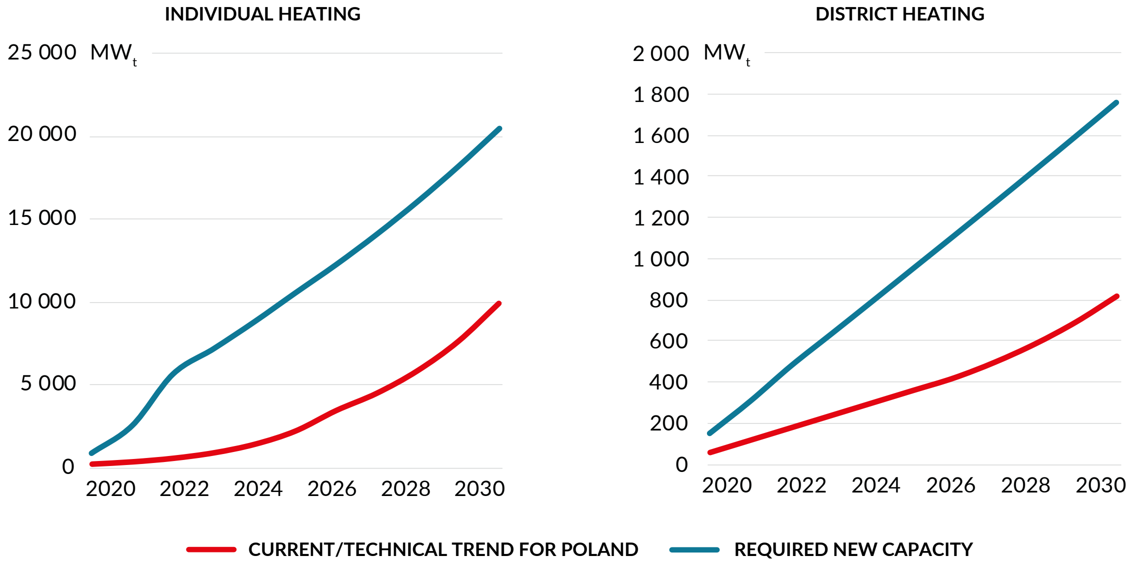
Collector systems can be beneficially combined with heat storage to store hot water when collectors produce more than the current demand for heat. Short-term storage tanks (with a capacity of several m^3), are available on the market and increasingly widely used. Also, seasonal storage facilities (long-term ones) should be more widely utilised in the years to come. In terms of LCOH, solar collectors as supplementary sources in heating systems are certainly the cheapest technology. Combined with seasonal heat storage, they are even more efficient.

17 W. Weiss, M. Spörk-Dür, *Solar Heat Worldwide. Global Market Development and Trends in 2018. Detailed Market Figures 2017*, AEE – Institute for Sustainable Technologies, Vienna 2015, https://www.iea-shc.org/Data/Sites/1/publications/Solar-Heat-Worldwide-2019.pdf.
18 According to the annual IEO survey.
19 For more information on storage tanks, see Section 6.6 on heat storage systems.
20 *Rynek kolektorów słonecznych w Polsce – 2015*, Instytut Energetyki Odnawialnej, Warsaw 2016.
21 *Rynek kolektorów słonecznych w Polsce – 2013*, Instytut Energetyki Odnawialnej, Warsaw 2014.
22 Assumption: 0.7 kW/m^2.

Development path

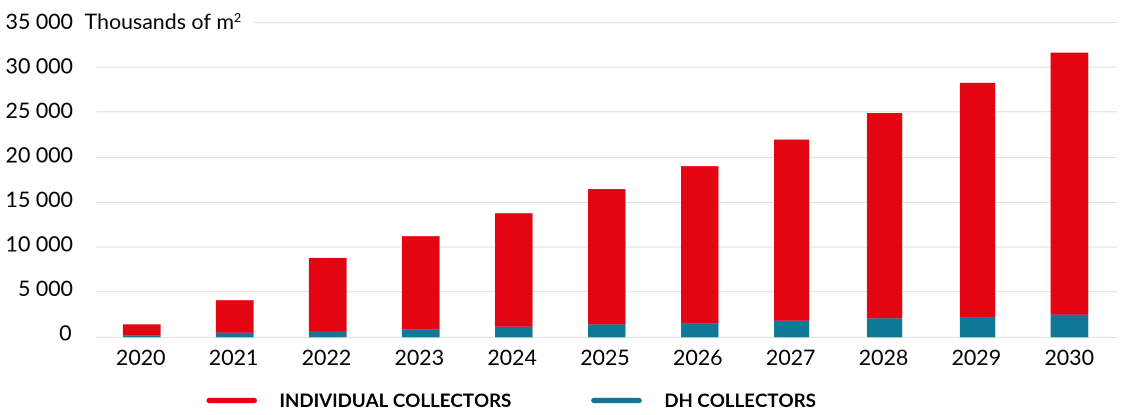
To achieve 40% RES share of the heating sector by 2030 requires the installation of additional solar collectors with power output slightly more than 22 GW_t, predominantly in private homes and residential estates. However, the current development trend is clearly insufficient.

Figure 4. Growth of installed capacity of solar collectors in individual heating and DH



Source: Developed by IEO.

Figure 5. Accumulated growth of surface area of solar collectors compared to 2019 (assumption: 0.7 kW_t/m^2)



Source: Developed by IEO.

Capital expenditures and selected key technical data

Table 4. Estimated averaged rates of costs for solar collector systems

Solar collectors	Capacity	Area	CAPEX	OPEX	LCOH
	MW_t	m[2a]	PLN/MW_t	PLN/MW_t/year	PLN/GJ
For households	0.004–0.05 (4–50 kW_t)	6–70	2,000,000 (2,000/kW_t)	16,000 (16/kW_t)	64
For public buildings	0.05–0.5	70–715	1,300,000 (1,300/kW_t)	6,000 (6/kW_t)	36
For solar heating systems (flat-plate)	>0.5	>715	1,160,000	900	30–50[b]

Source: Developed by IEO.

a – assumption: 0.7 kW/m².
b – The lower figure applies to the production of domestic hot water (without storage) and the upper one to systems with year-round energy storage facilities.

- Tests conducted in accordance with the following standard: PN-EN 12975-1+A1:2010 *Słoneczne systemy grzewcze i ich elementy – kolektory słoneczne. Część 1: Wymagania ogólne* (Thermal solar systems and components – Solar collectors. Part 1: General requirements) or equivalent.
- Certification based on a test report made by an accredited laboratory, as per the following standard: PN-EN ISO 9806:2017-12 *Energia słoneczna – Słoneczne kolektory grzewcze – metody badań* (Solar energy – Solar thermal collectors – Test methods) or equivalent.
- The testing report will be accompanied by a quality certificate issued by the relevant accredited certifying body. The date of confirmation of compliance with the required standard or of issuing a mark may not be more than five years from the date of the capital project.
- The power of solar collectors is determined as per standard PN-EN ISO 9806:2017-12 or equivalent, with temperature differences (Tm-Ta) = 50 K and solar radiation intensity (G=1000 W/m²) and is provided in the report of testing conducted in accordance with the above-mentioned standard.
- Solar collectors must have a manufacturer warranty of at least five years from the date of launching the system.
- A mandatory item of the system should be a heat meter separate from the monitoring system, installed on the circulation pipe of the solar collector to provide for local presentation of data (e.g., integrated with the system controls).

6.2. Biomass boilers

There are companies in Poland that offer boilers for burning various types of biomass, such as:

- wood chips – pieces of wood with dimensions ranging from several millimetres to a dozen or so centimetres, produced by grinding wood with machines;
- pellets – pressed granules from dry residues from the wood industry;
- dry and seasoned firewood.

There are also boilers for straw, cereal grains, production waste, and other seasonal plants. However, these are niche solutions, mainly for farming or industrial heat generation plants having access to their own production waste.

Table 5. Specifications of wood biomass

Type	Recommended use	Moisture (%)	Net Calorific Value (MJ/kg)
Wood chips	DH systems	20–60	6–16
Pellet	Private consumers	7–12	16.5–17.5
Firewood	Private consumers	20–30	11–22

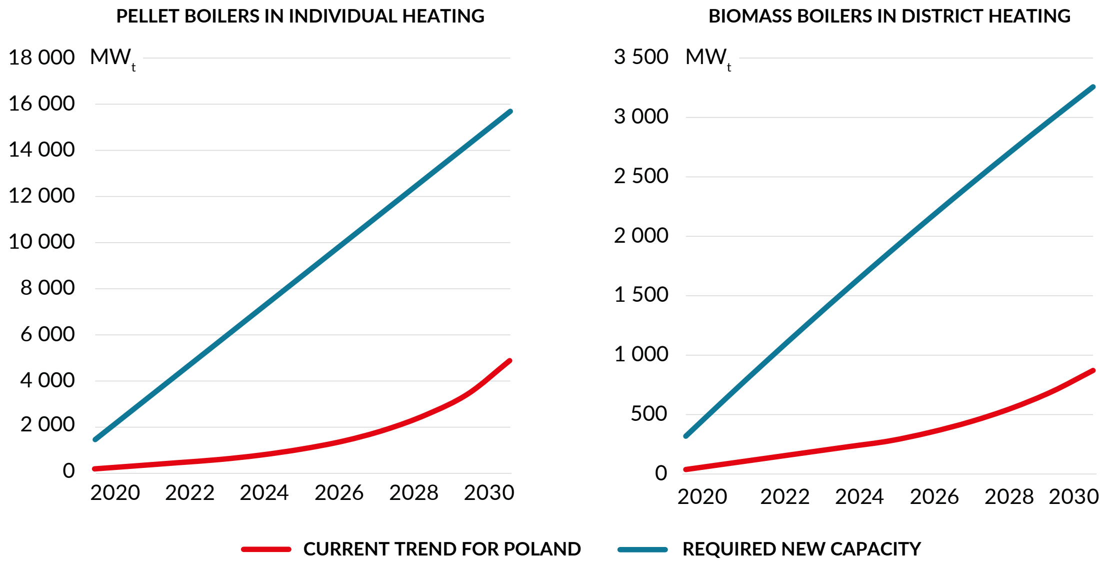
Source: Developed by IEO.

Wood biomass for individual heating systems

Pellet and firewood are used mainly in boilers for individual heating with power ranging from 4 to 500 kW_t. Modern pellet boilers are completely automated, the fuel being fed by a feeding screw. What is important here is the adequate quality of the granulate to prevent caking, which may damage the system. An innovative solution is a hybrid boiler that can be fed both with pellet and firewood.

To achieve the 40% RES share of heating sector in 2030, more than 860,000 new boilers, predominately using pellets, should be launched in the next decade. However, the current trend in this regard is unsatisfactory. It is important to note that this technology is considered transitional in decarbonisation of individual heating by 2050. In the nearest years, it will be used as a replacement of coal boilers in households. At the end of the useful service of these systems, other non-emission technologies will be introduced.

Figure 6. Biomass: growth of installed capacity in individual pellet boilers and boilers operated in DH



Source: Developed by IEO.

Wood biomass for DH

The installed capacity of large heating boilers fired with wood chips ranges from 500 kW_t to 20 MW_t. For boilers fired with wood chips, which contain more moisture (about 50%), it is important to determine the moisture content of the fuel burnt in such boilers. Excessive moisture could adversely affect the burning process, decrease the boiler's efficiency, and lead to its shorter useful life. A vast majority of these boilers are automated, with efficiency up to 87%. Catalogued types offered by manufacturers are of capacity up to 10 MW_t. They offer a very good alternative for obsolete designs of water-tube boilers in such a power range (e.g. WR-5). For larger units, it is necessary to place a customised order. Total installed capacity of biomass boilers in DH should rise by 3.2 GW_t by 2030, and combined heat and power systems using biomass by 665 MW_t.

Capital expenditures and selected key technical data

Table 6. Estimated averaged rates of costs for biomass boilers

Biomass boiler	Capacity	CAPEX	OPEX	LCOH
	MW_t	PLN/MW_t	$PLN/MW_t/year$	PLN/GJ
A small boiler with automated pellet fuel feeder	< 0.01 (<10 kW_t)	1,000.000 (1,000/kW_t)	350,000 (350/kW_t/year)	100
Biomass boiler for pellet – public buildings	0.01–0.5	600,000	340,000	83
Biomass boiler using wood chips for district heating	0.5–20	2,900,000	160,000	60

Source: Developed by IEO.

- Sizing of biomass boilers to ensure complete utilisation of the heat produced for the heating network or supply of a heat storage facility.
- Energy conversion efficiency of the boilers (Gross Calorific Value) of at least 85%.
- From 2014, meeting by new smaller biomass boilers of the requirement of PN-EN 303-5:2012 standard as per Commission Regulation (EU) 2015/1189[23] (in terms of emissions, these requirements are in the fifth class of that standard).
- Complying with the admissible emissions defined in the following documents:[24]
  - Directive 2010/75/EU of 24 November 2010 on industrial emissions for installations with at least 50 MW of total power delivered in fuel;
  - Directive (EU) 2015/2193 of 25 November 2015 on the limitation of emissions of certain pollutants into the air from a medium combustion plant (1–50 MW of energy contained in fuel).
- Having a manufacturer warranty of at least five years from the date of launch.

Sustainability criteria for biomass

In planning for the development of the use of biomass systems in heating, consideration should be given to the fact that in the near future some restrictions on its development will be imposed. This is because of the provisions of the new "RED II" Directive on the promotion of the use of energy from renewable sources for 2021–2030.[25] To reduce emissions from biomass burning,[26] large DH plants and Combined Heat and Power plants with a capacity of more than 20 MW_t using solid biomass will be covered by more stringent criteria for sustainable development and reduction of greenhouse gas emissions. For gaseous fuels from biomass, including biogas, this requirement refers to a plant with a total rated thermal input of at least 2 MW_t.

In addition, under Article 29 of the above-mentioned directive, a precondition to classify a biomass combustion plant as an RES plant is a reduction of greenhouse gas emissions by at least 70% for a plant in use from 1 January 2021 to 31 December 2025, and 80% for a plant in use from 1 January 2026.

Consequently, biomass, as a stable source, may supplement heating mixes but should not be used on a large scale as a basis for the coal-to-RES transition.

23 *Commission Regulation (EU) 2015/1189 of 28 April 2015 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for solid fuel boilers.*
24 These directives are implemented to the Polish legislation in the *"Environmental Protection Law" Act.*
25 *Directive of the European Parliament and of the Council (EU) 2018/2001 of 11 December 2018 on the promotion of the use of energy from renewable sources.*
26 Production of energy from waste and residue is not covered by this requirement.

6.3. Power-to-Heat technology

Power-to-Heat (P2H) refers to the idea of using electricity for heating purposes. The appliances identified in this section usually use electricity from the power grid, largely produced from coal, so they do not always contribute to the decarbonisation of the Polish heating sector.[27] That is why this report reviews the application of these systems in the *green* Power-to-Heat (gP2H) formula,[28] whose purpose is to manage the production of electricity from the cheapest RES. In particular, this applies to wind and solar sources in periods of the lowest price of power on the wholesale market or in the tariffs. If dynamic tariffs are introduced on the Polish market,[29] the application of the gP2H formula may lead to significant savings in household electricity bills.

From the district-heating perspective, the integration of electricity markets and heating systems along with storage facilities provides two basic benefits:

- storage of surplus electricity produced from RES in heat, which increases the opportunities to balance electric power systems based on the existing infrastructure.
- extra income of District Heating Utilities from sales of cheap, stored energy from RES as DH.

These opportunities open up a number of opportunities for cooperation between a number of entities, including:

- provision by District Heating Utilities of electricity market balancing services;
- no need for owners of wind farms to determine timetables of electricity input (e.g., purchase of clean energy by District Heating Utilities under the PPA model[30] or construction of a windmill on the company's premises);
- full adaptation to the requirements of the profile of demand for energy from the storage facility. Various quantities of energy can be drawn from the storage facility, as required by the system.

In Poland, the profile of heating demand is largely correlated to the profile of wind generation. We can assume that electricity prices in the autumn and winter seasons will be most favourable for the heating sector because these seasons feature the largest demand. It is another aspect that supports the integration of the electricity and heating sectors.

Due to the growing input of RES to the National Power System (NPS) and legislative changes aimed at making these sources operate on market terms, this potential can be expected to steadily grow in the future. In the current system environment, potential business results of such a plant may be underestimated by distribution and transmission fees. That is why it is necessary to develop appropriate market mechanisms and business models to enable effective integration of both sectors with benefits to both the electricity and heating sectors.

Four primary technologies are used in gP2H projects for the conversion of electricity into heat:

- resistance electric boilers,
- electrode boilers,
- resistance heaters,
- heat pumps.

The average costs of heating with electric power from RES (OPEX) under the gP2H formula, presented later in this report, do not take into account the cost of electricity. It depends on tariff groups and the scope of tariff regulation, including the profile of dynamic tariffs after 2020.[31]

27 According to Polskie Sieci Elektroenergetyczne, in 2019 about 75% of electricity was produced from lignite and hard coal.
28 To ensure RES share at 40% in 2030, only electricity from RES sources is taken into account. Guarantees of origin or a PPA contract may provide the consumer with 100% green electricity.
29 Dynamic tariffs reflect price fluctuations on spot markets. The opportunity to use them by end-consumers has been introduced by the *Clean Energy for All Europeans* package.
30 Long-term contracts for direct purchase of electricity from RES.
31 *Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity*

The existence of the market for heat pumps for several years now has allowed the Institute for Renewable Energy to propose estimated values of OPEX and LCOH, which incorporate ("black") electricity, to enable private consumers to better see the realities.

6.3.1. Resistance heaters

Resistance heaters are commonly used for heating domestic hot water. They can be flow-based devices or installed inside a heat storage facility. Resistance heaters work in conjunction with storage devices that accumulate heat in water (boilers).

For heating households, an interesting solution is thermal-storage stoves. These devices can draw cheap electricity during the time of surplus production of energy from renewable sources and release the accumulated heat during other times of the day. The air circulating inside the stove heats up and is later blown out to the room through slots.

Table 7. Estimated averages cost rates – resistance heaters

Resistance heaters	Capacity	CAPEX	OPEX
	MW_t	PLN/MW_t	PLN/MW_t/year
Boiler	0.001–0.027 (1–27 kW_t)	200,000 (200/kW_t)	8,000 (8 PLN/kW_t/year)
Thermal-storage stove	0.001–0.007 (1–7 kW_t)	700,000 (700/kW_t)	8,000 (8 PLN/kW_t/year)

Source: Developed by IEO.

6.3.2. Electric boilers

Resistance electric boilers work on the same principle as electric heaters of hot water. The Danish experience shows[32] that they are more suitable for small-scale solutions, from several kilowatts for single households to a maximum of 5 MW_t of installed capacity. Resistance electric boilers for individual consumers in the gP2H technology should collaborate with short-term water heat-storage facilities. Larger systems, with power of more than 2 MW_t, are parallel connections between several smaller units. Resistance boilers are usually connected to low-voltage grids.

Electric electrode boilers are designed for larger projects, and generating units for this type range from 1 to 50 MW_t (usually 5–50 MW_t).[33] A big advantage of such a solution is that, in addition to being flexible, they feature almost zero consumption of electric power when operated in stand-by mode. The transition of the electrode boiler in stand-by mode from 0 to 100% of power takes only about 30 seconds. Electrode boilers connected to medium-voltage grids for DH in P2H technology should work with seasonal heat storage facilities to achieve appropriate efficiency of the overall system.[34]

Development path

Eventually, almost 2 GW_t of installed capacity should operate under the gP2H formula in 2030 in DH systems and 1.2 GW_t in individual heating.

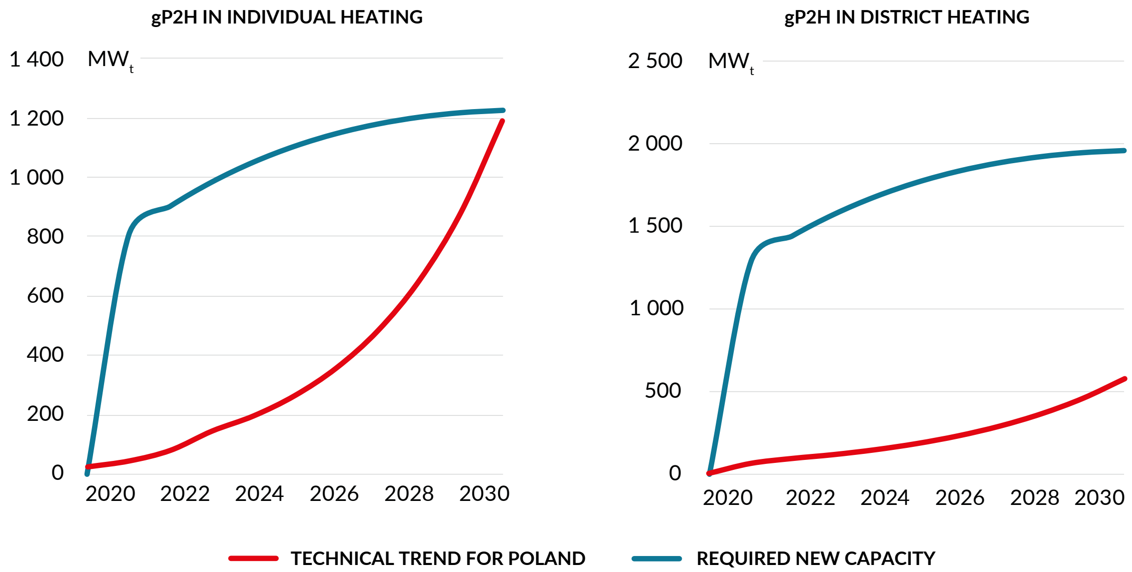
and amending Directive 2012/27/EU has not yet been implemented to the Polish legislation. That makes it impossible to provide a forecast for particular tariff groups until 2030.

32 *Technology Data for Generation of Electricity and District Heating*, August 2016, Danish Energy Agency, https://ens.dk/en/our-services/projections-and-models/technology-data/technology-data-generation-electricity-and.

33 Electric boilers are classified by their basic use into resistance boilers for individual consumers and electrode boilers for DH systems. However, other uses can be found.

34 Heat storage facilities can be integrated in various configurations with electric boilers (e.g., households—short-term storage facilities; DH systems—mid-term or seasonal storage facilities).

Figure 7. Growth of gP2H installed capacity: individual consumers and DH boilers



Source: Developed by IEO.

Capital expenditures and selected key technical data

Table 8. Estimated averaged cost rates for electric boilers

Electric boilers	Capacity	CAPEX	OPEX
	MW$_t$	PLN/MW$_t$	PLN/MW$_t$/year
Small resistance boilers (households)	0.004–0.05 (4–50 kW$_t$)	650,000 (650/kW$_t$)	6,500 (6.5/kW$_t$/year)
Large resistance boilers (public buildings)	0.05–5	670,000	6,500
Large electrode boilers	1–50	310,000	6,500

Source: Developed by IEO.

Resistance and electrode boilers:

- Must have rated energy conversion efficiency at >98%.
- Should be equipped with a stand-by mode that allows for quick startup (from 0% to 100% of power in less than a minute).
- Must have a manufacturer's warranty of at least five years from the date of launching the system.

6.3.3. Compression heat pumps

Heat pumps are already a mature technology and increasingly present in Poland. With the gradual reduction of emission rates from the country's electric power system, heat pumps will be based more and more on power from RES. Compression heat pumps can use electric power in the gP2H formula for operating the compressor. The heat is usually distributed through the central heating system. These can be both water-based and air-based systems using fan coil units or ventilation systems.

Currently, about 200,000 such systems operate, of which half are used for central heating.[35] Depending on the selection of the heat source, several types of heat pumps can be distinguished:

1. **Air-based heat pumps (air-to-air[36] or air-to-water)** are most popular in Poland. They are usually low power (4–50 kW_t) and are used primarily by households. These pumps use the energy accumulated in the ambient air or the air discharged from the building.

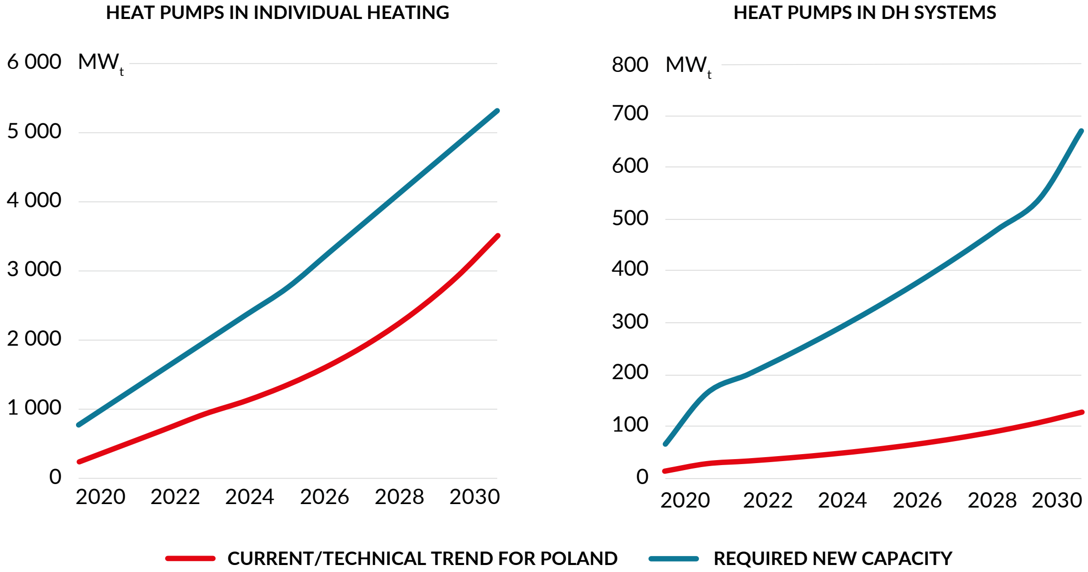
2. **Water-to-water heat pumps** use the energy accumulated in underground, surface, or sea water. Where underground waters are easily accessible, two boreholes are made. One of them is the well from which water is drawn to the heat pump. The other borehole is the discharge well. The advantage of water-based heat pumps is their particularly high efficiency due to high water temperatures as a heat medium. These are usually low-power pumps (4–50 kW_t), and their main users are households.

3. **Ground-source heat pumps (brine-to-water or ground-to-water)** take heat from the ground using vertical or horizontal heat exchangers in which water flows directly or indirectly through a medium—brine. The crucial component of the cost of such heat is the capital expenditure for building the lower source. Ground-source heat pumps, sized correctly to meet heating requirements of a building with a good energy efficiency standard, can operate in monovalent mode (without an additional source of heat) throughout the entire heating season. They are used usually in new homes with higher energy efficiency standards. They can be also used on DH systems (power capacity of more than 1 MW_t) as an element supporting the production of heat.

Development path

To achieve a 40% RES share in the heating sector in 2030, demand in the DH system is estimated at an additional 670 MW_t, and several times more in single-family houses and residential estates—5.3 GW_t (about 300,000 new units). Like the previously discussed technologies, the current pace of growth of heat pumps in Poland is insufficient.

Figure 8. Heat pumps: growth of installed capacity in individual heating and DH systems



Source: Developed by IEO.

35 *Rynek pomp ciepła w Polsce w latach 2010–2018. Perspektywy rozwoju rynku pomp ciepła do 2030 roku*, PORT PC, Kraków 2019.

36 Because external air is a lower source of heat, at lower temperatures (-5 degrees Celsius or less), the COP of the pump is assumed to fall so low that the system becomes an electric heater (COP ~ 1).

Capital expenditures and selected key technical data

Table 9. Estimated averaged rates of costs for heat pumps

Heat pumps	Capacity	CAPEX	OPEX	LCOH
	MW_t	PLN/MW_t	$PLN/MW_t/year$	PLN/GJ
Low-capacity heat pumps (ground-source)	<0.05	5,000,000 (5,000/kW_t)	270,000 (270/kW_t/year)	131
Low-capacity heat pump (air-to-water)	<0.05	3,500,000 (3,500/kW_t)	350,000 (350/kWt/year)	111
Heat pump – application in non-residential buildings (ground-source)	0.05–1	2,500,000	550,000	139
Heat pump – application in non-residential buildings (air-to-water)	0.05–1	2,000,000	530,000	150
Heat pumps – application in DH systems	1–5	2,940,000	70,000	90

Source: Developed by IEO.

- Building vertical ground-based exchangers must be preceded by a plan of geological works or a plan of maintenance of a mining establishment, and notification to the appropriate authority of the intention to undertake such works.
- The heat pump's coefficient of performance (COP) must be at least 4.
- The installation of heat pumps involves interference with the soil of the plot of land and in some cases it is necessary to comply with the formalities required by the *Act of 9 June 2011 "Geological and Mining Law"* regarding boreholes in mining areas and with the depth more than 30 m. In such circumstances, it is necessary to prepare a plan of geological works to be submitted for acceptance to the district authority.
- With the installation of ground-source heat pumps, it is possible to use the potential of water bodies, wells, or watercourses as the lower source of heat, in accordance with the Geological and Mining Law and, in addition, with the *Act of 18 July 2001 "Water Law".*

6.4. Heat pumps combined with photovoltaic installation

The popularity of photovoltaic systems has been growing. In 2019 alone, new systems achieved more than 800 MW of installed capacity.[37] So far associated mainly with the production of electricity, these systems can work also with heat pumps to increase energy self-sufficiency of buildings and save costs in heating. Electric power processed in photovoltaic units can be used to drive compressors of heat pumps, which then heat domestic hot water and support the central heating system. In Polish conditions, about 20-35% of the annual demand of heat pumps for electric power can be met directly by photovoltaic panels.

Photovoltaic systems that work with heat pumps can be classified as:

- centralised units with power above 500 kW_p;
- distributed units on public buildings and in households with capacity of 1–500 kW_p. A special group are household microsystems, which usually do not exceed 10 kW_p.

Microsystems with power of up to 50 kW_p operate in what is called a "discount system",[38] i.e., "netting" with the supplier

37 Based on data from Polskie Sieci Elektroenergetyczne.

38 The "discount" system enables one to store the produced energy from the panels in the power grid and re-collect 80% of that energy during the year (for PV systems < 10 kWp, or 70% for 10 - 50 kWp). Clearing is made on an annual basis only up to the level consumed by the prosumer. Potential unused surplus is supplied to the grid for free, which encourages, auto-consumption.

of electricity for homes, small companies, or housing cooperatives on an annual basis. Their profitability in that system depends on what is called the auto-consumption rate, which shows how much energy in the building during the year is met by its own system. A typical rate for a single-family house is about 30%. It can be increased by installing, e.g., an electric boiler or a heat pump. Systems with power output of more than 50 kW_p in offices, industry, or public facilities do not use the netting system and benefit even more from an increased auto-consumption rate (auto-consumption rate is 60% on average, but it is relatively easy to achieve 70%).

Capital expenditures[39] and selected key technical data

Table 10. Estimated averaged rates of costs for photovoltaic systems

Photovoltaic system (working with a heat pump or hot water storage)	Capacity	CAPEX	OPEX
	MW_p	PLN/MW_p	PLN/MW_p/year
Home systems for household purposes	0.004–0.05 (4–50 kW_p)	5,500,000 (5.500/kW_p)	57,000 (57/kW_p/year)
Application in non-residential buildings	0.05–0.5	3,000,000	47,000

Source: Developed by IEO.

- For photovoltaic modules, meeting standards (International Electrotechnical Commission, IEC), as confirmed by a certificate from an accredited certifying unit. The principal standard is IEC 61730-1 and -2 (general verification of electric and mechanical safety). Additionally, there are standards depending on the type of photovoltaic cell: IEC 61215 (crystalline silicon c-Si), IEC 61646 (thin-film cells), IEC 61215-1-4:2016 (CIGS cells), IEC 61215-1-2:2016 (CdTe cells), IEC 61215-1-3:2016 (amorphous silicon-based cells, a-Si).
- Correct selection of the power of photovoltaic system to the needs of buildings also supplied by a heat pump. Underestimated power output would result in no savings, and excessive rated power would unnecessarily increase the financial loss of the prosumer by giving too much energy to the grid for free.
- Appropriate selection of the inverter to the applied photovoltaic system. An inverter with too low power will not fully use the potential of the PV panels, and excessive-rated power would unnecessarily increase capital expenditure.

6.5. Biogas

Systems of a biogas plant in Combined Heat and Power (CHP) mode provide for the possibility of combining electricity and heat generation. They are characterised by higher efficiency of the generation process (even up to 90%), because with the same quantity of fuel they generate electric power and heat at the same time. Currently, three types of biogas plants operate in Poland, with a combined installed capacity of 239 MW_p:[40]

- in farming,
- in landfill sites,
- in wastewater treatment plants.

The use of heat from CHP for heating purposes is, however, restricted by the fact that only a small part of the developing biogas plants will be able to supply heat to an external or local heating network, much less residential units. Most of them are and will be located far from DH systems and residential estates. The opportunities in this regard must by analysed in the context of local conditions.

39 The costs of such hybrid system are practically additive.
40 Figures from the Energy Regulatory Office as at 30 June 2019.

Agricultural biogas plants

Agricultural biogas plants with thermal capacity of about 1–5 MW_t are usually built at food processing plants, which provide continuous input of material for the generation of biogas. They use the thermal power they generate for the purposes of their own facility and any surplus can be sold to the nearby DH network. An alternative is to build biogas plants near towns surrounded by rural areas, from which the plant would take in the materials necessary for the process.

Another approach is small agricultural biogas plants (thermal input 50–200 kW_t) and microplants (up to 50 kW_p). The construction of small agricultural biogas plants as part of the process of plant or animal production can be profitable in the model of distributed agriculture represented in Poland. Heat from such plants can be effectively used in, e.g., drying facilities or heating of residential or commercial buildings.

Landfill biogas plants

Landfill biogas plants are adapted to the disposal of landfill waste and the acquired energy is mainly used for feeding industrial processes and for the landfill's own purposes. If a biogas plant is to be built on landfill sites, the capital expenditure for the construction and operation of the degassing installation should be taken into account. The cost of construction[41] of such a biogas plant is high compared to the benefits from energy generation and income from sales. From the owner's point of view, it is rather an opportunity to usefully get rid of waste rather than the production of energy for business purposes.

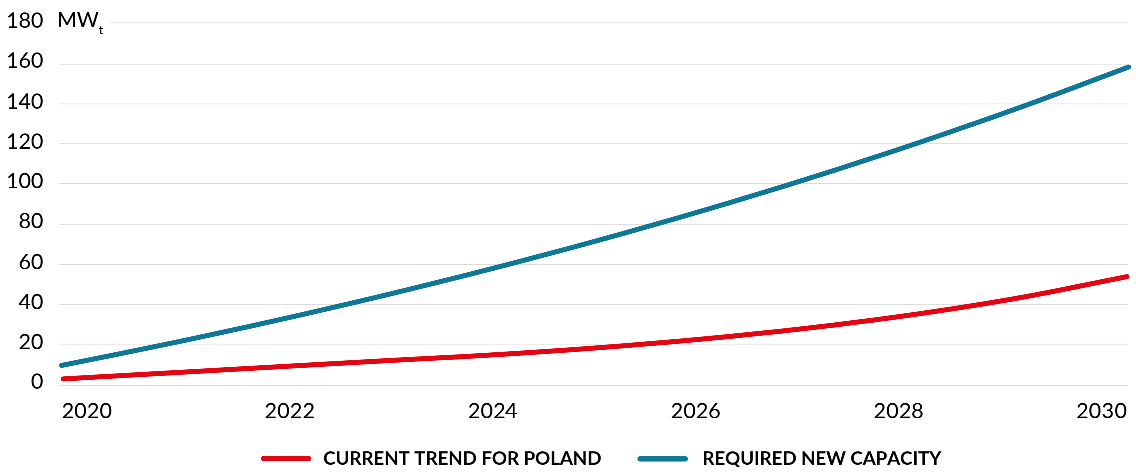
Biogas plants at wastewater treatment plants

Wastewater biogas plants are built by water and wastewater utilities at wastewater treatment plants, where significant amounts of waste sediments are produced as a by-product. The energy generated from biogas is used mainly for the wastewater treatment plant's own purposes due to its high demand for electric power and heat. The use of biogas produced from the material available on the spot reduces the consumption of conventional resources and saves emission of pollutants from their incineration. Only a small portion of the generated energy can be supplied to a nearby DH network or directly to the industrial establishments nearby.

Development path

Due to the limited possibilities of using biogas for heating purposes, the scenario provides for only 157 MW_t of new capacity. So far, the development of this market in Poland has been limited[42] and the target will not be achieved if the trend is maintained.

Figure 9. CHP biogas: growth of installed capacity



Source: Developed by IEO.

41 Landfill sites are usually located further away from cities than, e.g., wastewater treatment plants. Capital expenditure for the construction of a biogas plant itself are apparently lower, but the cost of connection of such biogas plant to the DH network is high.

42 According to the figures from the Energy Regulatory Office, in 2005–2019 biogas capacity grew only by 207 MW_p.

Capital expenditures and selected key technical data

Table 11. Estimated averaged rates of costs for biogas systems

Biogas – CHP plant	Capacity	CAPEX	OPEX
	MW_t	PLN/MW_t	$PLN/MW_t/year$
Agricultural biogas plants	0.2–5	9,500,000	3,000,000
Biogas plants in landfill sites	0.2–1	5,000,000	600,000
Wastewater biogas plants	0.2–1	13,000,000	550,000

Source: Developed by IEO.

- A report should be drawn up concerning the environmental impacts of agricultural biogas plants with rated electric power of more than 0.5 MW.
- Biogas plants should be located at least 300 m from residential areas[43] to limit potential adverse impacts from noise emission (>40db), combustion gases or odours, or the consequences of potential failures.
- Biogas plants should be located in the near vicinity of farmland. An average biogas plant with electric power production of 1 MW needs post-fermentation mass of 1000–5000 ha of agricultural land.

6.6. Heat storage facilities

RES potential in the heating sector and RES efficiency have been growing rapidly with the development of heat-storage technology working in cycles lasting several days and up to entire seasons. The choice of heat storage facility is affected by the availability of land and hydrogeological conditions, and the required volume capacity of the tank depending on the size of the solar system. Example recommendations based on literature are provided in Table 12.

Table 12. Description of short- and long-term accumulation of heat in solar heating systems with DH networks

Item	Short-term heat storage	Long-term heat storage
Minimum size of the plant	30–40 residents (maximum up to 60 residents)	100–150 residents
Tank capacity	0.05–0.1 m^3/m^2 of surface area of the collector	1.5–4 m^3 / MW_t or 1.4–2.1 m^3/m^2 of surface area of the collector
Share of solar radiation energy	Domestic hot water – 50% central heating + domestic hot water – 10-20%	central heating + domestic hot water – 40-70%

Source: Developed by the authors based on T. Schmidt, D. Mangold, *Large-Scale Thermal Energy Storage—Status Quo and Perspectives*, Malmö 2013..

6.6.1. Seasonal storage facilities

Seasonal storage facilities are used primarily for the accumulation of surplus energy from renewable sources (especially solar heat) and from CHP plants in the summer season. These are based on technology already commercialised in certain European countries, e.g., in Denmark, Germany, Sweden, and the Netherlands. In Poland, the first small-scale

43 *Przewodnik dla inwestorów zainteresowanych budową biogazowni rolniczych*, Instytut Energetyki Odnawialnej, Warsaw 2011.

pilot system, working with a heat pump and solar collectors, was established in 2014 in Ząbki. Most common are systems based on water or water-and-gravel storage, but there are four types:

- Tank Thermal Energy Storage, TTES. It is a tank made of reinforced concrete, stainless steel, sometimes glass reinforced with plastics, filed with water, with the capacity ranging from several cubic metres to several thousand;
- Pit Thermal Energy Storage, PTES. A mixture of soil or gravel with water is used for the storage of heat. Important characteristics include porosity and permeability, as well as compressive strength;
- Aquifer Thermal Energy Storage, ATES. Natural, closed underground water bodies used for the accumulation of heat. Water from those tanks is heated upon extraction and then pumped back into the deposit;
- Borehole Thermal Energy Storage, BTES. Heat is accumulated in a ground layer.

Seasonal heat storage facilities involve high capital expenditures that can be reduced with larger storage size. To achieve the appropriate effects of scale and maximise the benefits, such storage facilities should be implemented in a system with a relatively high energy intake (a residential estate of multifamily units or larger) while for the smallest systems, the decentralised concept of the introduction of solar heat should be used.

Capital expenditures[44] and selected key technical data

Table 13. Estimated cost rates for seasonal heat storage facilities

Heat storage facilities	Capacity	CAPEX		OPEX
	MWh	PLN/MW$_t$	PLN/MWh[a]	PLN/MW$_t$/year
Seasonal – TTES	3–1,500	400,000	10	1,700
Seasonal – PTES	5,000–40,000	389,000	6	2,000
Seasonal – ATES	30–800	7,500,000	12	7,500[b]

Source: Developed by IEO.

a – per charging/discharging cycle.

b – higher OPEX is related to the consumption of electricity for the operation of pumps.

- Due to optimisation of heat losses and costs, the size of seasonal storage facilities is recommended to be at least 1,000 m^3.
- Water is the medium to store and transfer heat.
- The heat storage facility should have its own thermal installation and average losses of stored heat should be less than 15 W/m^2 of the tank's surface area (as calculated in accordance with generally applicable rules).
- Seasonal above-ground storage (TTES) can be designed and built in a similar way as large surface fire tanks with proper permissions.
- If an underground or pit storage facility is to be built, a hydrogeological survey should be conducted in terms of stratigraphy, soil compactness, drift of underground waters, hydraulic conductivity of the ground, intensity and direction of flow of groundwater and other waters.
- The size and location of hydraulic connections to the tank should be designed in such a way as to optimise the efficiency of the charging/discharging process.

44 BTES storage facilities are still in the semi-experimental phase and there are no reliable data on costs.

6.6.2. Short- and mid-term storage facilities

The function of short- and mid-term storage facilities is current optimisation of energy/heat because they can store energy/heat for several hours or days. Short-term storage facilities are used mainly by individual consumers. Mid-term storage facilities are used both by individual consumers and small DH plants, which use them to optimise the operation of CHP units, i.e., to even out the daily mismatch between the demand for heat and the demand for electricity.

In RES heating systems for individual consumers using such storage facilities, heat is accumulated in thermally insulated steel tanks with single or double coil exchangers, with appropriate capacity. The volume capacity of such tanks can range from several hundred litres for small heating systems with power output of 10-50 kW_t up to 5,000 litres for very large systems with a power output of several hundreds of kilowatts. Depending on demand, they are usually connected in a series. Charging/discharging such a storage facility usually depends on the source of heat, consumption of heat, and the respective size of the heat storage facility, as well as the charging and discharging equipment.

Hot water tanks are usually made of steel or reinforced concrete, or glass reinforced with plastics. The walls of the tank and the layer of ground are sealed with plastic film, which must be resistant to temperatures up to 80°C. The outer thermal insulation should be 15-30 cm thick.[45]

Capital expenditures and selected key technical data

Table 14. Estimated averaged rates of costs for short- and mid-term heat storage facilities

Heat storage facilities	Capacity	CAPEX		OPEX
	MWh	PLN/MW_t	PLN/MWh[a]	PLN/MW_t/year
Short-term	0.003–0.03	275,000	245	1,000
Mid-term, e.g., for solar collectors for domestic hot water	0.5–350	117,000	80	1,720

Source: Developed by IEO.

a – per charging/discharging cycle.

- A short-term heat storage facility also can also be built as an above-ground tank.
- The heat tank should have thermal insulation. Average losses of stored heat should be less than 15 W/m² of the tank's surface area (as calculated in accordance with generally applicable rules).
- Seasonal above-ground storage can be designed in a similar way as large above-ground fire tanks with proper permissions.
- The size and location of hydraulic connections to the tank should optimise the efficiency of the charging/discharging process.
- Storage facilities and the entire systems can be designed and assembled only by people with valid Office of Technical Inspection (UDT) permissions.

6.7. Geothermal heating modules

Production of heat from geothermal sources is a very attractive solution for municipal heating systems, but this also depends on the geological conditions of the facility's location. Geothermal waters are usually 1.5 to 3.5 km deep, with varying temperatures; the temperature of rock formations 2-2.5 kilometres deep does not exceed 100°C. Heating modules fed from boreholes (geothermal stations with heat exchangers) are customised projects that depend on the conditions of the geothermal deposit.

45 G. Wiśniewski, S. Gołębiowski, A. Więcka, K. Kurowski, *Kolektory słoneczne. Energia słoneczna w mieszkalnictwie, hotelarstwie i drobnym przemyśle*, Warsaw 2008, p. 109.

Geothermal sources can provide a stable, but less flexible basis for heating systems supplied so far by coal- or gas-fired boilers. It is sufficient to connect the geothermal module to the network and disconnect the boiler, which will be started up at very low air temperatures.[46] In addition, high capital expenditures for boreholes and geothermal systems require seeking year-round heat consumption. Such conditions are met by using geothermal heat in District Heating Utilities for heating domestic hot water.

However, limited technical capacity and business considerations effectively hold back the development of this technology in Poland. Only some District Heating Utilities have so far opted for investing in geothermal sources. Geothermal energy technologies are still considered a novelty and involve a number of engineering and operational difficulties. The need to make boreholes generates high investment costs in geothermal sources.

Current level of heat use from geothermal sources and the potential

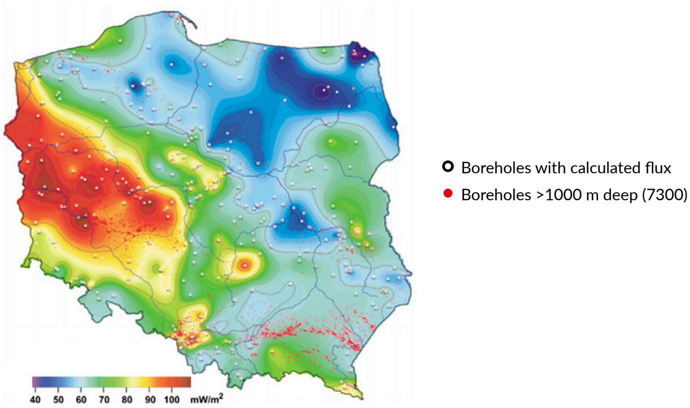
Seven geothermal plants currently operate in Poland (Table 15). The Institute for Renewable Energy estimates that 37 other cities are properly situated to use the available geothermal resources, and can consider utilising these resources, including deep ones.[47] The most prospective zone, with a high temperature of underground water (85-100°C), is the north-eastern part of the Mogilno- Łódź Basin, with 19 towns identified in this regard. An additional 18 towns are situated in the Polish Lowlands, in the following regions: Zachodniopomorskie, Lubuskie, Wielkopolskie, Dolnośląskie, and Opolskie.

Table 15. Geothermal heating plants in Poland

City/town	Year established	Geothermal power (MW_t)
Bańska Niżna	2001	4.5 (target: 70)
Pyrzyce	1996	15 (target: 50)
Stargard	2012	14
Poddębice	2015	10
Mszczonów	2001	7.3
Uniejów	2006	2.6
Toruń (in implementation phase)	2020	25

Source: Developed by IEO.

Figure 10. Map of the density of the thermal flux in Poland



Source: J. Szewczyk, D. Gientka, *Mapy gęstości strumienia cieplnego na obszarze Polski*, Państwowy Instytut Geologiczny – Państwowy Instytut Badawczy, Warsaw 2009.

46 Geothermal heating plants are usually not particularly efficient at temperatures below 0°C to cover the entire demand and must be supported by peak sources.

47 *Możliwości wykorzystania odnawialnych źródeł energii w Polsce*, Instytut Energetyki Odnawialnej, Warsaw 2007. The authors have drawn the data necessary for assessing the economic potential of geothermal energy from utilities situated in suitable geothermal zones.

Table 16. Cities and towns with suitable conditions for geothermal heating plants

Chodzież	Jarocin	Międzychód	Poznań	Września
Choszczno	Kalisz	Namysłów	Rawicz	Zduńska Wola
Głogów	Konin	Oborniki	Sieradz	Zgierz
Gniezno	Kościan	Oleśnica	Słupca	Złotów
Goleniów	Krotoszyn	Opole	Szczecin	Żnin
Gorzów Wielkopolski	Kutno	Piła	Turek	
Gostyń	Łęczyca	Police	Wałcz	
Gryfino	Łódź	Polkowice	Wągrowiec	

Source: *Możliwości wykorzystania odnawialnych źródeł energii w Polsce*, Instytut Energetyki Odnawialnej, Warsaw 2007.

Development path

For geothermal heating, the statistical growth of new capacities until 2030 is 15 MW_t, which means that three large units of 5 MW_t capacity each would be built. Such relatively small growth is due to the increased capacity factor of geothermal units versus Scenario IV from the Forum Energii report.[48]

Capital expenditures and selected key technical data (resulting from economic recommendations)

Table 17. Estimated cost rates for geothermal modules

Geothermal heating plant	Capacity	CAPEX	OPEX	LCOH
	MW_t	PLN/MW_t	PLN/MW_t/year	PLN/GJ
Geothermal module	0.5-50	5,380,000	107,500	111[a]

Source: Developed by IEO.

a – current prices of heat from Polish heating plants using geothermal energy are between PLN 48 and PLN 83/GJ pre-VAT.[49]

- The heating plant should be situated directly over the geothermal water source. The power output of the heating plant should be higher than the demand for heat in the summer season.
- Geothermal water should have a relatively high temperature (close to the supply temperature in the DH network), high and stable output throughout many years of operation, and relatively low salinity.

7. Delivery of the identified technology solutions

There is a high disproportion between what the scenario presented in this analysis proposes regarding the pace of growth of RES technology and what has been actually implemented in recent years in Poland. The biggest challenges are mainly faced by the heating sector based on the conversion of biomass into energy, which has stagnated (in particular regarding DH without CHP) and the *green Power to Heat*, *gP2H*, which has not existed in Poland yet.[50] The closest to achieving the adopted assumptions and entering the necessary path of development are individual solar collectors and individually operated heat pumps. These technologies enjoy increasing interest and should be further developed.

Such an ambitious pace of development projects can result in shortages of manufacturing capacity of the necessary technology due to scale problems with Polish companies, which have not needed to employ large workforces in

48 Increasing the capacity factor with the same volume of energy generated in geothermal units results in lower growth of installed capacity.
49 See: L. Pająk, W. Bujakowski, "Zmiany ceny zakupu energii cieplnej pochodzącej z polskich ciepłowni geotermalnych w latach 2007–2018 w świetle obowiązujących taryf rozliczeniowych", *Technika Poszukiwań Geologicznych. Geotermia, Zrównoważony Rozwój* 2018, no. 1, https://min-pan.krakow.pl/wydawnictwo/wp-content/uploads/sites/4/2018/10/03-PajakBujakowski.pdf.
50 Regulations to reduce the price of unbalanced electric power to zero (Intra Day Market) have applied only since the beginning of 2020.

recent years and are confronted with the need to expand their manufacturing output. It seems necessary to tap market demand and expand the capacity of the national sector for the manufacture and construction of RES systems, including the development of the R&D sector.[51] However, this process needs time, from two to five years. That is why quick growth of capital spending in RES in the Polish heating industry in 2020–2025 will require the involvement of foreign companies, which will significantly increase their output capacity in Poland and join the supply chain of necessary parts of heating systems.

Development of incentives for investing in heating systems based on RES, expected because of the absence of or slower path of development, does not mean that new capacities will spring up instantly. When planning the growth of installed capacity divided into DH (large) units and individual (significantly smaller) units, investment cycles for each technology should be considered. There is the time that must pass from the owner taking a decision to building the respective system to putting it into use. This time will be spent mainly on the analysis of development options, selection of contractor, acquisition of funding (subsidies, bank loans), preparation of the design of the installation, and proper construction works. Regarding small heating systems in households, the growth of investment will be restricted not so much by the length of the development cycle but by the pace of growth of the network of construction companies in the supply chain throughout the country.

Table 18. Estimated development cycles for the technologies considered in this report

Technology	DH systems (years)	Household systems (years)	Public buildings (years)
Biomass boiler	2.5	0.25	0.25
CHP Biomass	2.5	–	–
Solar collectors	0.5	0.2	0.2
Heat pumps	0.75	0.25	0.25
Agricultural biogas plants	2	-	–
Landfill biogas plants	2	–	–
Sewerage biogas plants	2	–	–
Geothermal	4.5	–	–
Power to Heat	0.75	0.25	0.75
Short-term storage facility	–	0.1	0.15
Mid-term storage facility	0.35	0.1	0.15
TTES	0.5	–	–
PTES	1	–	–
ATES	0.5	–	–

Source: Developed by the authors based on IEO and Danish Energy Agency (DEA).

8. Assumptions for analyses and working methodology

Verification of scenario

Scenario IV has been verified, updated, and adapted to the requirements of this paper regarding the technologies possible to be applied in DH and individual heating,[52] including in terms of what is called *capacity factors* of particular heat sources (MWh/MW or h/year). The effect of modification on the demand for heat and scenario of development of

51 Such an opportunity is provided by the new programme of the National Research and Development Centre – Quick Path "Heating Systems", https://www.ncbr.gov.pl/programy/fundusze-europejskie/poir/konkursy/konkurs-8-1-1-1-2019/.

52 The adopted scenario did not analyse in terms of technology the "Manufacturing Industry and Construction" sectors, which play an important role in demand for specific technologies. For instance, processes with heat recovery technologies have not been considered. With time, such technologies will become a source of heat in municipal heating systems, in particular in industrial agglomerations, such as Warsaw, Katowice, and others.

generation capacity is presented in the *Introduction* to this report. Modifications regarding the technologies are made only in such aspects as:

- **Biogas** – installed capacity for heating purposes was reduced to about 235 MW_t.
- **Heat pumps for individual applications –** growth of thermal input to about 9 GW_t is assumed. In 2030, air-to-water heat pumps will have about a 70% share.
- **Biomass** – the plan for development of biomass capacity has been intensified due to lower production of heat from the above-mentioned sources. In DH systems, production of energy both for boilers and CHP based on biomass increased by about 20%. For the individual heating sector, the biomass sources were disaggregated into two fuels: firewood and pellet. Currently, firewood is significantly more used, and pellet is used on a smaller scale. For 2030 in individual heating, a significant growth in the share of pellets and decrease in firewood is anticipated.
- ***Power-to-Heat*** – production of heat from this source was increased in the DH sector, and added as a separate category in the individual heating sector.

Growth of installed capacity

Another stage of analysis was to verify how rapidly the installed capacity will grow for particular technologies compared to their average growth in several recent years in Poland. For technologies not used in Poland yet (e.g., electric boilers in DH systems), the experiences of the Danish DH system are adopted as a benchmark, extensively described by the Danish Energy Agency (DEA). The purpose of that comparison is to illustrate the extent of the changes that must be made in Poland's heating sector to achieve such quick and thorough decarbonisation.

Table 19. Average growth of installed capacity of the respective technology in Poland in recent years

Technology	Average growth in Poland in recent years (MW_t/year)	Technical trend for Poland based on DEA (MW_t/year)
Biomass - DH	120	–
Biomass - individual	100[53]	–
Solar collectors - DH	–	60
Solar collectors - individual	250	–
Heat pumps - DH	–	60
Heat pumps - individual	230[d]	–
Biogas	3	–
Geothermal	1.2[a]	–
P2H - DH	–	30
P2H - individual	25[b]	–

Source: Developed by IEO.

a – it is difficult to talk about a trend in recent years for geothermal heating because only a few geothermal heating plants have operated in Poland since the 1990s. Figures were adopted based on the average capacity of a standard heating plant (5 MW_t) and investment cycle for such technology (4.5 years).
b – *green Power to Heat* technology has not been operational in Poland yet, so the average growth is based on the increase of installed capacity for ordinary electric boilers.
c – for technologies not used in Poland yet, figures from *Technology Data for Electricity and District Heating* were used.
d – *Rynek pomp ciepła w Polsce w latach 2010–2018. Perspektywy rozwoju rynku pomp ciepła do 2030 roku*. PORT PC, Kraków 2019, http://portpc.pl/pdf/raporty/Raport_PORTPC_wersja_final_2019.pdf.

53 *Rynek urządzeń grzewczych w Polsce w 2018, Raport SPIUG*. Warsaw 2019, https://spiug.pl/raporty/rynek-urzadzen-grzewczych-w-polsce-w-2018-roku/.

Standard installed capacities

In the next step, the growth of installed capacity was disaggregated into the quantity of capital projects by selecting the standard capacity of a system in each technology. For individual projects, the forecast growth of capacity was split into low-capacity systems for households and medium-capacity ones for public buildings. As a result, we calculated the quantity and capacity of systems to be built from 2020 to meet the requirements of the scenario until 2030.

Table 20. Standard capacities of systems used in various segments of the heating market

Technology	District heating (MW_t)	Households (kW_t)	Public buildings (kW_t)
Biomass	6	10	100
Biomass - CHP	10	–	–
Solar collectors	3	5	50
Heat pumps	2	10	70
Agricultural biogas plants	2	–	–
Landfill biogas plants	0.7	–	–
Sewerage biogas plants	0.7	–	–
Geothermal	5	–	–
Power-to-Heat	2	5	50

Source: Developed by IEO.

Costs

In the last step, the total cost of transformation of the Polish heating sector until 2030 was calculated. The CAPEX figures necessary for the analysis of the technologies were taken from several sources, including many reports by the Institute for Renewable Energy, figures from the Danish Energy Agency, the Joint Research Centre (JRC), and the International Renewable Energy Agency (IRENA).

Biomass availability and costs

In addition, of particular concern was the demand for energy biomass, not only due to economic added value but also due to the risks related to the potential inability to supply biomass in a sustainable and environmentally safe way. Market balance also should be achieved between consumption for energy and non-energy purposes (wood industry).

Due to the high growth of the number of biomass incineration units, annual consumption of biomass for newly built units and the annual cost of biomass for these units was also estimated.[54]

54 The following data are used in the calculations: efficiency of biomass boiler: 85%; efficiency of CHP unit: 90%; heat-to-power ratio: 0.4; net calorific value of wood chips: 13 GJ/t; gross calorific value of wood chips: 17 GJ/t; gross calorific value of wood pellets: 19 GJ/t; average price of biomass: PLN 25/GJ.

Table 21. Annual consumption of biomass, including new units from 2020

Consumption of biomass (kt)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Biomass (wood chips) boilers	695	867	1,039	1,211	1,383	1,555	1,727	1,898	2,070	2,242	2,414
Biomass (wood chips) - CHP	2.,349	2,431	2,513	2,594	2,676	2,757	2,839	2,921	3,002	3,084	3,165
Firewood	4,817	4,467	4,117	3,767	3,417	3,067	2,718	2,368	2,018	1,668	1,318
Pellet	1,889	2,198	2,507	2,816	3,125	3,434	3,743	4,052	4,361	4,670	4,979
Annual TOTAL	**9,750**	**9,963**	**10,176**	**10,388**	**10,601**	**10,813**	**11,027**	**11,239**	**11,451**	**11,664**	**11,876**

Source: Developed by IEO.

The growth of consumption of biomass for energy by more than 2 million tonnes, from 9.8 million tonnes in 2020 to 11.9 million tonnes in 2030, should not result in turbulence in the market for biomass solid fuels. It is possible if there is a gradual but not parallel significant growth of demand for biomass in the electricity sector.

Table 22. Annual cost of biomass, including new units from 2020

Cost of biomass (PLN billion)	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Biomass (wood chips) boilers	0.23	0.28	0.34	0.39	0.45	0.51	0.56	0.62	0.67	0.73	0.78
Biomass (wood chips) - CHP	0.764	0.790	0.817	0.843	0.870	0.896	0.923	0.949	0.976	1.002	1.029
Firewood	2.288	2.122	1.956	1.789	1.623	1.457	1.291	1.125	0,.958	0.792	0.626
Pellet	0.897	1.044	1.191	1.338	1.484	1.631	1.778	1.925	2.072	2.218	2.365
Annual TOTAL	**4.17**	**4.24**	**4.30**	**4.36**	**4.43**	**4.49**	**4.55**	**4.62**	**4,.68**	**4,.74**	**4.80**

Source: Developed by IEO.

Annual value of biomass for heating sector, assuming no inflation and no increase in real prices, will be PLN 4.8 billion in 2030. (PLN 4.2 billion in 2020)

Appendix:
Data sheet of modern RES technologies in the heating sector

RES technology	Capacity	CAPEX	OPEX	LCOH	LCOH	Manufacturers of systems, solution vendors
	MW	PLN/MW$_t$	PLN/MW$_t$/ year	PLN/GJ	PLN/MWh	
Biomass boiler						
Small boiler with automated pellet fuel feeder	< 0.01	1,000,000	350,000	100	360	Altereco Plus, Cichewicz, Galmet, Danstoker, Gras Energia, Graso, Granpal, Sefako, Rafako, Kotłospaw, Witkowski, Defro, Wentor, Kostrzewa, Rakoczy
Biomass boiler for pellet – public buildings	0.01–0.5	600,000	340,000	83	300	
Wood-chip biomass boiler for heating plants	0.5–20	2,900,000	160,000	60	216	
Solar collectors						
Solar collectors for households	0.004–0.05	2,000,000	16,000	64	230	Sunex, Kospel, Galmet, Ensol, Arcon Sunmark, Hewalex
Solar collectors for public buildings	0.05–0.5	1,300,000	6,000	36	130	
Flat-plate solar collectors for solar heating systems	>0.5	1,160,000	900	30–50[55]	108–180	
Electric heating (for gP2H technology)						
Boiler	0.001–0.027	200,000	8,000	–	–	Lemet, Termica, Danstoker, Elterm, Kospel, Elektra, Stiebel Eltron, Henimax, Elektromet, Termet
Thermal-storage stove	0.001–0.007	700,000	8,000	–		
Small resistance boilers (households)	0.004–0.05	650,000	6,500	–	–	
Large resistance boilers (public buildings)	0.05–5	670,000	6,500	–	–	
Large electrode boilers	1–50	310,000	6,500	–	–	

55 The lower figure applies to the production of domestic hot water (without storage), the upper one—systems with year-round energy storage facilities.

RES technology	Capacity	CAPEX	OPEX	LCOH	LCOH	Manufacturers of systems, solution vendors
	MW	PLN/MW$_t$	PLN/MW$_t$/year	PLN/GJ	PLN/MWh	
Heat pumps[56]						
Low-capacity heat pumps (ground-source)	<0.05	5,000,000	270,000	131	470	Vaillant, Viessman, Nibe-Biawar, Galmet, Hoval, Junkres, Ferroli, Fonko, F.U. GEJZER, Vatra, Hibernatus, Bosch, Buderus
Low-capacity heat pump (air-to-water)	<0.05	3,500,000	350,000	111	400	
Heat pump – application in non-residential buildings (ground-source)	0.05–1	2,500,000	550,000	139	500	
Heat pump – application in non-residential buildings (air-to-water)	0.05–1	2,000,000	530,000	150	540	
Heat pumps – application in DH systems	1–5	2,940,000	70,000	90	324	
Photovoltaic system (working with heat pump or hot water storage)						
Home systems	0.004–0.05	5,500,000	57,000	–	-	Viessmann, Vaillant, Hewalex, Kospel, Stilo Energy, Soltec
Application in non-residential buildings	0.05–0.5	3,000,000	47,000	–	-	
Geothermal heating plant						
Geothermal module	0,5–50	5,380,000	107,500	111	400	G-Drilling, Geotermia Toruń

56 Because of the existence of the market for heat pumps, the Institute for Renewable Energy has for several years given estimated values of OPEX and LCOH, which incorporate ("black") electric power to enable private consumers to better see the realities (G12 tariff for households, C12a for public buildings).

RES technology	Capacity	CAPEX	OPEX	LCOH	LCOH	Manufacturers of systems, solution vendors
	MW	PLN/MW$_t$	PLN/MW$_t$/ year	PLN/GJ	PLN/MWh	
Heat storage facilities						
Short-term - for biomass and *Power-to-Heat*	0.003–0.03 MWh	275,000	1,000	-		Short-, mid-term: Elektromet, Termica, Termet, Lemet Kospel Seasonal: Sunmark Arcon, Galmet, Rafako
Mid-term – for solar collectors for domestic hot water	0.5–350 MWh	117,000	1,720	-		
Seasonal – TTES	3–1.500 MWh	400,000	1,700	–		
Seasonal – PTES	5000–40,000 MWh	389,000	2,000	–		
Seasonal - ATES	30–800 MWh	7,500,000	7,500	–		
Biogas – CHP plant						
Agricultural biogas plants	0.2–5	9,500,000	3,000,000	181	650	CES, Viessmann, Horus Energia, Eneria, Poldanor, RenCraft, KWE - AB Energy Polska
Biogas plants in landfill sites	0.2–1	5,000,000	600,000	56	200	
Wastewater biogas plants	0.2–1	13,000,000	550,000	111	400	

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