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A preliminary techno-economic analysis of the potential of using municipal waste gasification installations in a hybrid electricity generation system

Abstract: This paper presents the results of modeling and analysis of hybrid generation system (HSW). The system contains municipal waste gasification installation, photovoltaic (PV) system and wind farm. The system cooperates with the power system to provide electrical energy to the communal consumer. The consumer is characterized by a maximum power demand equal to 10 MW and an annual energy demand of 42.351 GWh. Generation with renewable sources was modelled using meteorological data. Moreover, in order to cover the demand with the level of generation, gas storage was used. Next, the three-stage gasification model is presented. It was validated, using the literature data, and its efficiency and gas composition have been calculated and are presented. Furthermore, energetic and economic analysis have been conducted. Installed power usage factor and efficiency of energy sources were calculated. Gross and net energy generation of hybrid generation systems have been computed and are presented. In this analysis, energy consumption by gas compressing was included. The analyzed HSW covered 54.5% of the demand. Most of this (30.2%) was covered by the gasification system. However, the system was characterized by a low net efficiency equal to 16.7%. Diagrams of power generation in each source and storage fill chart are presented. In the

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economic part of the analysis, results of calculations of net present value and payback period are published in order to examine the profitability of the system.
The cost of electricity was 490–1050 PLN/MWh. The results show that municipal waste gasification can be used as a part of HSW to adjust the generation with the demand. Moreover, it can be economically advantageous. However, it is characterized by high CO_2 emission and low efficiency of the waste processing system.

Keywords: hybrid generation system, municipal waste gasification, cost of electricity generation, electricity generation system modelling

Introduction

Due to the nature of the power system, it is necessary to balance electricity generation with demand. In Poland, it has been balanced using controllable power plants based on fossil fuels and system-scale electrical energy storages (EESs) such as pump-storage plants. However, in order to achieve climate goals, it is necessary to change the structure of the power generation system and to increase the share of renewable energy sources (RES). According to the data acquired from the Polish TSO Polskie Sieci Elektroenergetyczne (Polish Power Grids), between December 2019 and December 2021, the capacity of RES doubled (Report 2021 KSE). Due to the small installed capacity of the sources, the vast majority of them is distributed generation. Power generation in RES is variable and depends on both daily and seasonal factors. The factors are, inter alia, wind speed and direction (wind turbines), radiation (photovoltaic sources) and the water flow of a river(run-of-river power plants). Because of the stochasticity of the sources, there is the need to balance generation and demand. This can be realized by controllable power plants, EESs or by formation of hybrid generation systems (HSW). HSW contains the combination of different renewable and non-renewable energy sources and/or EESs. This allows for the better adjustment of the generation to the demand, and compensation for disadvantages and the use of the advantages of all technologies. What is more, their power output is less dependent on weather and season (Kamiński and Pietracho 2019). Using controllable sources, HSW allows to build self-balancing systems (Paska et al. 2019). The currently used EESs are characterized by high costs of investment and operational problems, such as low energy density (e.g. supercapacitors), geographical limitations (pumped storage power plants and pneumatic energy storage), fuel that is difficult to produce and hazardous (fuel cells) and toxicity (some batteries) (Paska 2017). Moreover, the use of conventional sources results in the CO_2 emission and is associated with the constantly increasing costs of emissions.

Another problem in modern day countries is the increase in the amount of municipal waste, which is correlated with an increase in the standard of living (Wielgosiński 2020). Due to high environmental costs, there is a necessity for reducing the waste stream going to landfills. Additionally, it is forbidden to landfill waste with gross calorific value higher than six MJ/kg (Ordinance of the Minister... 2015). The bill of December 14, 2012 introduced a waste hierarchy. In order of the most preferred, these are: prevention, reuse, recycling, other recovery processes (including energy recovery) and disposal (Waste Act of December 14, 2012). In a circular economy, only the part of waste that is no longer fit for use in any of the higher-ranked ways should be recovered for energy. This waste belongs to the over-sieve fraction which is separated in mechanical-biological processing plants. It constitutes 30–45% of the mixed waste stream and has a high calorific value, which means that it cannot be disposed of in landfills. Moreover, due to its good flammable properties and the relative stability of its composition, it is suitable for thermal energy recovery (Primus and Rosik-Dulewska 2018). According to estimates, after sealing the waste-management system, despite the increasing number of operating and planned waste-to-energy plants, even about 1.5 million Mg of unprocessed over-sieve fraction may remain (Wielgosiński 2020). As a result, there is a need to expand the capacity for energy recovery from waste, including small installations that can cooperate with other energy sources as part of distributed generation and hybrid systems.

In Poland, research on HSW focuses mainly on the use of RES and EESs. There is a lack of studies that include biomass or waste gasification in HSW. However, there is some papers focused on this topic outside Poland. All of them contain RES (mainly PV but sometimes also wind sources) and EESs, especially batteries. For example, such systems have been examined to power the University of Victoria campus (Esfilar et al. 2021) or to cover the demand of part of tVancouver (Bagheri et al. 2018). Digesters (Singh and Basak 2022) and fuel cells and hydrogen storage instead of batteries (Zahedi et al. 2021) have also been tried. Systems with fuel cells were the only option which used gas storage. Other systems used batteries to cover the demand. Usually, they did not take into consideration forms of cooperation with the grid. However, it has been concluded (Eliasu et al. 2022) that the optimal form of a cooperation grid-gasification system is to cooperate rather than have independent work of the system or the grid.

The paper presents an energy analysis of the use of the waste gasification system to supplement generation from renewable sources and the profitability analysis of such an installation in order to check whether this technology has the potential to be used in HSW.

1. Municipal waste gasification

In Poland, all municipal waste-to-energy plants (ITPOK) are using direct combustion of mixed municipal waste and/or fuel from waste. However, apart from direct combustion, there are other technologies known for recovering energy from waste: gasification, pyrolysis and plasma technologies.

The fuel is not completely oxidized in the gasification process. The amount of oxidant must be less than the stoichiometrically necessary for the combustion process, so that the products, in addition to CO_2, are also CO, H_2 and CH_4. Gasification agents may be air, oxygen or steam, and the energy efficiency of this process, due to the necessary energy input, is always lower than 100% (Wacławiak 2007). Both exothermic and endothermic processes take place inside the gasification reactor, which makes the mathematical model of this process very complicated. The generated gas can be used in boilers as well as in engines and gas turbines (Jamrozik et al. 2015). However, they must be specially adapted to this, because this gas contains significant amounts of hydrogen and carbon monoxide, and its lower calorific value is in the range of 4–12 MJ/Nm^3 (Skorek and Kalina 2005). In the case of fixed bed reactors, there are several reaction zones: drying, pyrolysis, gasification, combustion, and slag (Skorek and Kalina 2005). Figure 1 shows these zones in fixed bed gasifiers.

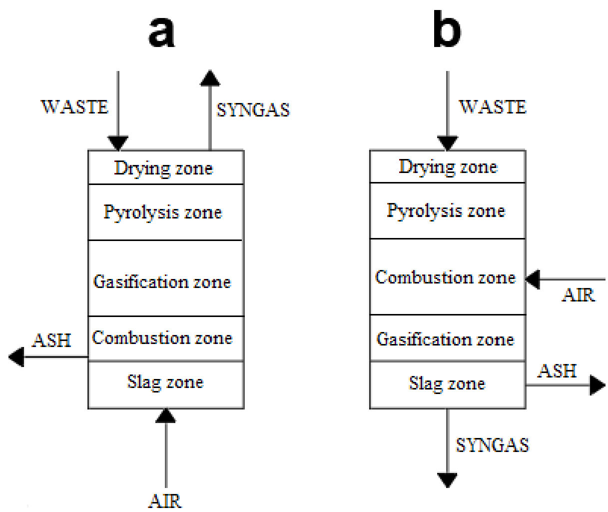

Fig. 1. Fixed bed gasifiers
a) updraft, b) downdraft

Rys. 1. Reaktory zgazowania
a) przeciwprądowe, b) współprądowe

Gasification of waste has both advantages and disadvantages compared to incineration. An important negative aspect is the need to prepare the waste for the gasification process. Due to the fact that gasification is a surface reaction, the fuel must be of an appropriate size. Moreover, the fuel should be dry and the composition should be relatively constant, which limits the use of mixed municipal waste as fuel (Wacławiak 2007). However, when processing only the over-sieve fraction, this problem can be avoided. The advantages of this technology include the possibility of cleaning the syngas between the gasification reactor and the gas combustor, which enables avoidance of the application of restrictive emission standards for waste-to-energy plants (Primus and Rosik-Dulewska 2017). It also allows the use of gas combustion technologies, such as gas turbines or reciprocating engines, with a higher level of efficiency than the incineration of waste. Another advantage occurs when gas is burnt in a boiler – a reduction of the corrosiveness of the heating surfaces can be achieved (Wielgosiński 2020).

Due to the possibility of storing syngas and the use of the sources with a short start-up time (e.g. gas turbines) for the combustion of the gas, it is possible to use these technologies in HSW to balance the generation from RES with the demand.

2. Model of a hybrid power generation system

The HSW system was modeled in the Ebsilon®Proffesional software. This system consists of a connection to the power grid, a photovoltaic farm, a wind farm and a gasification waste-to -energy plant that balances the generation with the demand in the system. The gasification plant includes a gasification and syngas cleaning module, a gas storage and gas turbines. In order to maximise the efficiency and to reduce the minimum power with which the system can operate, two turbines were used. Figure 2 shows the HSW.

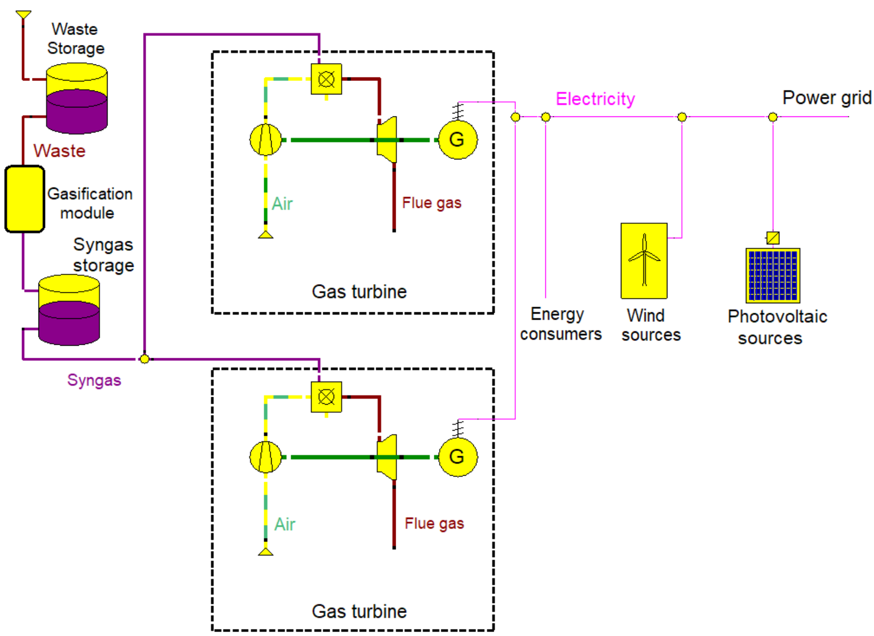

Fig. 2. HSW model

Rys. 2. Model HSW

The PV components in the software were described as monocrystalline. It was placed directly to the south with a tilt of 40°. It was using maximum power point tracker but did not use sun trackers. The farm consisted of 200 Wp panels. The power generation was calculated using the solar radiation and sun position in the intervals' time. This resulted in taking into account the angle of incidence of sunlight. The wind turbine component used wind data converted to the hub height of 130 m. It calculated the power generation based on internal power characteristics.

The profile of the municipal residual consumer based on data from the Enea Operator (Standard energy consumption profiles for 2021) was adopted for the analysis. The maximum power demand was 10 MW, and the annual energy consumption was 42.351 GWh. The energy demand corresponds to 21,175 apartments with a total energy consumption of 2 MWh. The annual distribution of demand is shown in Figure 3. What is more, the average daily demand distribution was determined and is shown in Figure 4.

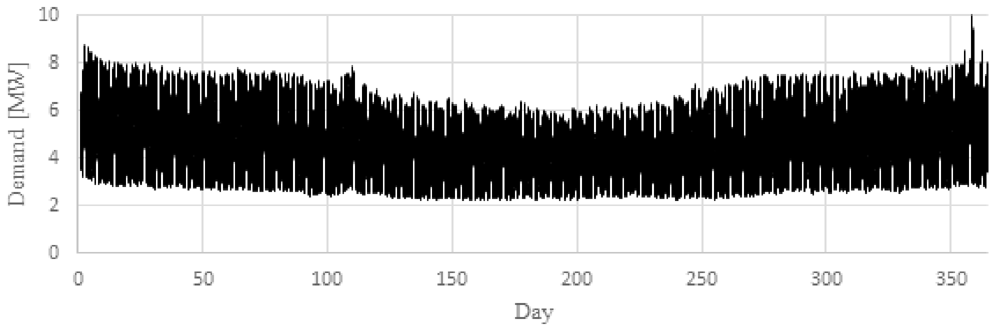

Fig. 3. Annual energy demand distribution

Rys. 3. Roczny rozkład zapotrzebowania

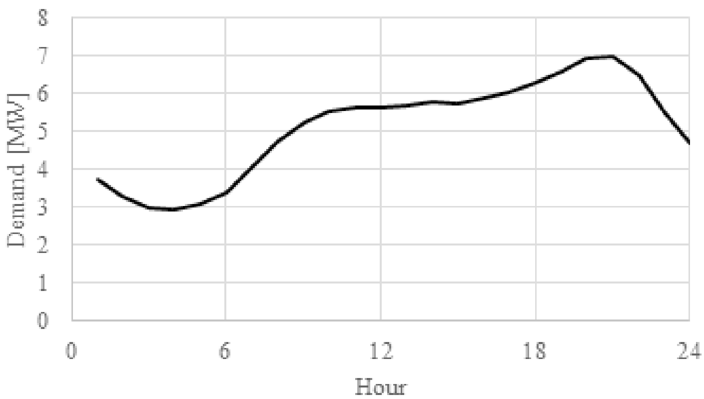

Fig. 4. Average daily demand distribution

Rys. 4. Średni dobowy rozkład zapotrzebowania

Often, the most advantageous form of cooperation between HSW and the power grid is covering the base of the load by the grid. This is due to the impact on the power grid of such an installation (Ceran and Sroka 2016). In the analyzed system, it was assumed that the power from the grid would be constant and equal to the lowest electricity demand. In order to limit the surplus electricity generation, it was assumed that the sum of power from renewable sources would be calculated according to Equation 1. The capacity of single sources was adopted as guaranteeing the minimal redundant generation of electricity and ensuring reasonable energy generation

$$P_{RES} = P_D - P_{grid} \tag{1}$$

where:

P_{RES} – the sum of the power of RES,
P_D – maximum power demand,
P_{grid} – power from the grid.

The total power of gas turbines was determined as 7 MW, which was equal to the maximum difference between the energy demand and the sum of the generation in RES and the power supplied from the grid. The capacity of the gas storage was calculated in such a way as to avoid too fast an unloading of the storage and to minimize the number of start-ups. The start-up and stabilization of the gasification process takes several hours, which makes it necessary to limit their number. Furthermore the storage capacity was limited by the increasing investment cost. Table 1 shows the input data for the HSW model.

Table 1. Input data of HSW

Tabela 1. Dane wejściowe HSW

Data	Value	Unit
Power from grid	2.2	MW
Nominal power of the wind farm	5	MW
Nominal power of the photovoltaic farm	2.8	MW
Nominal power of a single gas turbine	3.5	MW
Nominal efficiency of the gas turbine	37.0	%
Gas storage capacity	450	Mg

The logic of the system operation is described in this paragraph. The power grid supplied the energy consumer with a stable power level of 2.2 MW. The RES generated electricity stochastically and depending on the weather. If the sum of power from the grid and from RES was not able to cover the demand, the gas turbines were used. However, if the sum was higher than the demand, the RES generation was reduced in order to maintain constant power from the grid. In all intervals, it was assumed that the generation and demand are stable at the time of the interval (10 minutes).

3. Model of municipal waste gasification plant

A municipal waste gasification plant was modelled within the Ebsilon®Proffesional software. The plant uses a downdraft reactor, a gas-cooling module and a gas-cleaning module. In order to model the gasification process as accurately as possible, three separate components were used. Each of these was responsible for a single reaction zone in the reactor. The installation is shown in Figure 5. It consists of: a pyrolysis zone (1), a combustion zone (2), a gasification zone (3), an air heater (4), a synthesis gas cooling and cleaning module (5) and a two-stage compressor (6).

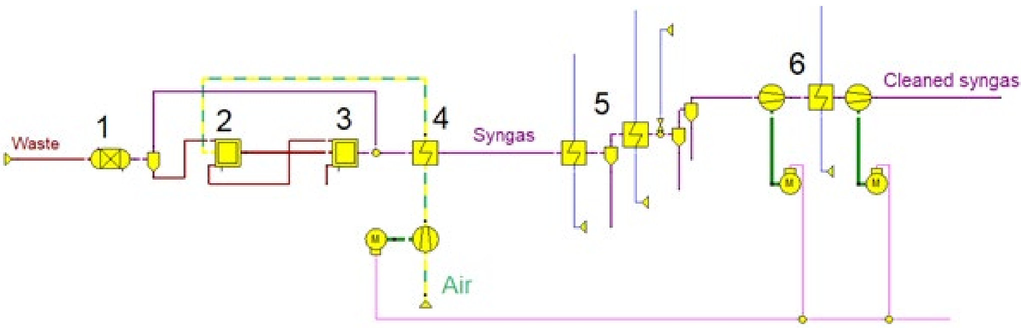

Fig. 5. Gasification installation model

Rys. 5. Model instalacji zgazowania

The modelled reactor calculates the composition of the gas generated. The amount of energy that is released or absorbed by each processes is calculated by minimizing the Gibbs free energy function. The amount of air for the gasification process has been defined as minimal ensuring a non-negative energy balance of the reactor, i.e. the exoenergetic processes taking place in the reactor provide heat for endoenergetic processes.

The model was validated by comparing the syngas composition obtained as a result of the modeling with the results of real installations from the gasifier manufacturer (Minutillo et al. 2017). The validation results are presented in Table 2.

TABLE 2. Gasifier model validation

TABELA 2. Walidacja modelu instalacji zgazowania

Gas component	% vol.					
	CO	H_2	CO_2	CH_4	N_2	O_2
Model	21.77	17.78	11.59	3.22	45.81	0.00
Data (Minutillo et al. 2017)	21±3	16±4	11±3	1.75±0.75	50	0.55±0.35

The obtained gas composition is very similar to the literature values. Among the combustible components, only the share of methane exceeds the values in the actual system. The shares of both CO and H_2 are slightly higher than the average, but they are within the range for this reactor. The greater share of nitrogen in the literature data provides proof about using more air for gasification.

Based on the average composition of the over-sieve fraction (Primus and Rosik-Dulewska 2018) and the average elemental composition of various wastes (Meraz et al. 2003), the elemental composition of the reactor feed was determined and the gasification process was then simulated. Moreover, according to Formula 2 (Wacławiak 2007), its efficiency was determined. The results are presented in Table 3.

$$\eta = \frac{\dot{m}_{gas}\, Q_{wgas}}{\dot{m}_{waste}\, Q_{wwaste}} \tag{2}$$

where:

η – efficiency [–],
m – mass flow [kg/s],
Q_w – lower calorific value [kJ/kg],
gas – syngas,
waste – waste.

Table 3. Parameters of municipal waste and cleaned syngas

Tabela 3. Parametry odpadów i oczyszczonego gazu syntezowego

Waste	% mas.								MJ/kg	t/h
	C	H	S	N	O	Cl	Ash	H_2O	Q_w	Mass flow
	40.89	5.13	0.09	0.61	24.29	0.97	15.20	12.81	16.096	2.93
Syngas	% vol.					%	MJ/kg		MJ/Nm^3	t/h
	CO	H_2	CO_2	CH_4	N_2	η	Q_w		Q_w	Mass flow
	23.31	19.05	8.14	3.86	45.73	80.92	5.972		5.675	6.39

The proportions of the components are mostly in the range achieved by downdraft reactors, with a slight excess of CO and a reduced amount of CO_2. Moreover, the calorific value of this gas is also confirmed by both the literature sources (Skorek and Kalina 2005) and the actual test systems (Kardaś et al. 2017).

When modeling the gasification system, it was assumed that it could only work in two states: 100% load and 0% load.

4. Energy analysis

In order to perform the analysis, the meteorological data from the IMGW [X1] and typical meteorological years for the city of Poznań were used. On their basis, the distribution of electricity production in RES and the necessary generation in gas turbines was calculated in Ebsilon Professional software. The radiation data were firstly linearly interpolated to 10-minute intervals and were then calculated in the software. The wind data was already acquired in 10-minute intervals. In addition to municipal consumers, the demand includes energy consumption for the internal load during gasification (mainly for compression of syngas). Figure 6 shows the distribution curves for two selected days.

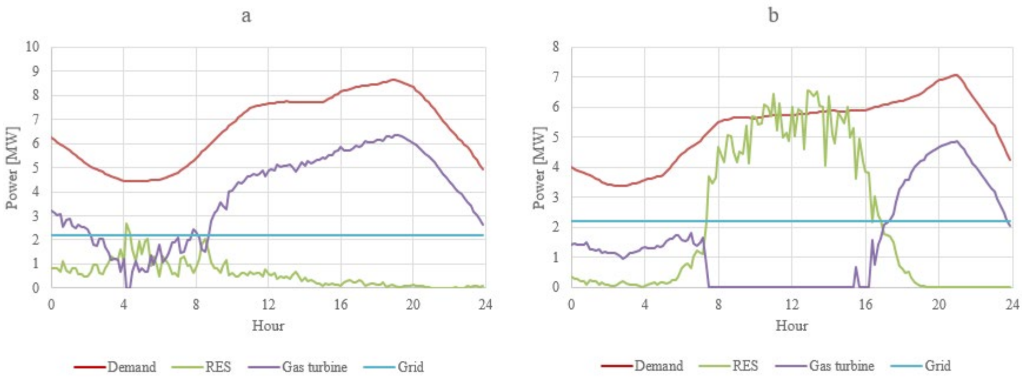

Fig. 6. Generation and demand on
a) January 1 b) July 30

Rys. 6. Przebiegi zapotrzebowania i generacji w dniu:
a) 1 stycznia b) 30 lipca

Figure 6b shows that in the afternoon hours of summer months, due to the significant amount of photovoltaic sources and the lack of electricity storage, the generation from renewable sources exceeds demand. This energy has to be sold or the generation from renewable sources must be limited. The author assumed that surplus generation from RES is limited.

Figure 7 shows a diagram of the storage capacity and the operation of the syngas generator during the year. As a result of the use of this storage, the number of startings per year was reduced to twenty-three, and the minimum operating time of the gasification system was over 147 hours.

The energy analysis of hybrid system includes: capacity factor T, average gross and net generation efficiency (η_{brutto} and η_{netto}), annual electricity generation Agen, annual energy consumption by HSW A_{pob}, annual net electricity generation A and CO_2 emission E_{CO_2}. The data were calculated both for the HSW and for individual sources. The results are presented in Table 4.

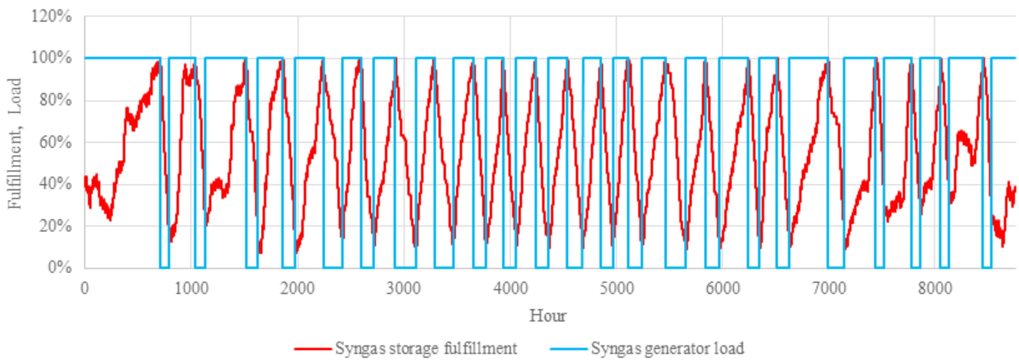

Fig. 7. Gas storage fill chart

Rys. 7. Wypełnienie magazynu gazu

TABLE 4. Results of the energetic analysis of HSW

TABELA 4. Wyniki analizy energetycznej HSW

Data	T	η_{brutto}	η_{netto}	A_{gen}	A_{pob}	A	B	E_{CO_2}
Unit	h	%	%	MWh	MWh	MWh	Mg	t/MWh
HSW	1,559	–	–	28,767	5,611	23,079	17,218	1.059
Wind farm	1,613	–	31.2	8,070	–	8,070	–	–
Photovoltaic farm	789	–	12.9	2,209	–	2,209	–	–
Gasification system	2,641	24.0	16.7	18,488	5,688	12,800	17,218	1.909

The analyzed hybrid system covers approximately 54.5% of the demand: 19.1% is covered by the wind farm, 5.2% by the PV farm, and 30.2% by gas turbines.

The gasification plant is characterised by the largest capacity factor. However, due to its function, it is still less than 1/3 of the year. The gasification system efficiency is 24%, which also results from the part-load operation and takes into account the gasification efficiency. Moreover, due to the need to compress the gas, the net efficiency drops by another 7.3 percentage points.

The capacity factors for RES are lower than in literature. PV in Poland should have theoretical capacity factor between 9.5–11.5% (832.2–1,007.4 h) and in the region of Greater Poland wind turbines' theoretical capacity factor could reach up to more than 25% (Piasecki et al. 2019). Such a low capacity factor is the result of a reduction of RES's generation when it exceeds demand. However, it shows how real systems could work.

The HSW emissions (1,059 kg CO_2/MWh) are higher than emissions from generation systems in Poland (698 kg CO_2/MWh) (KOBiZE 2021). However, the HSW deals with the over -sieve fraction problem. If this waste is stored on landfills, they could emit CO_2 and CH_4 which has higher global warming potential or it could burn without energy recovery. In this paper, the potential emission from landfilled waste was not calculated; therefore, the analysis of avoided emission could not be conducted. The emissions are higher than in wind-solar power plants which generates electricity without CO_2 emissions.

5. Economic analysis

In order to analyze the profitability of the described system, the investment costs Kn and operating costs Ke of individual HSW fragments were estimated. The results are presented in Table 5. Currently, ITPOK is not subject to CO_2 emission fees. However, due to their planned inclusion in the EU ETS, options were considered with fees to the amount of 0 PLN/Mg, 200 PLN/Mg and 400 PLN/Mg.

Table 5. Investment and operating costs

Tabela 5. Koszty inwestycyjne i eksploatacyjne

Element	Kn [mln PLN]	Ke [mln PLN/year]
Wind farm	38.43**	0.85**
Photovoltaic farm	13.51**	0.22**
Installation of waste storage, gasification, syngas purification and storage	43.90*	4.58*
Installation of electricity generation from syngas	55.74*	
Sum	151.58	5.66

* Own study.
** Based on (IRENA 2020).

The determined investment costs for the amount of processed waste are higher than those resulting from the estimates in the literature. The costs of the gasification installation amount to PLN 2,525.45 per Mg of waste processed during the year, where in (Kwaśniewski et al. 2018) they amount to PLN 1357. This is due to inflation and the fact that the installation is not operating all year round, so the costs related to the treated waste are high.

Due to the dynamically changing prices of electricity, it was decided to calculate the payback period for the energy price range of 450-1200 PLN/MWh. Moreover, the levelized cost of electricity (*LCOE*) was calculated. In addition to selling electricity, the installation would generate profits from waste disposal. The calculations were carried out for the following three values of the "gate fee": 250 PLN/Mg, 350 PLN/Mg, 450 PLN/Mg. The lifetime of the installation is twenty years, and the construction time is two years. The calculations also take into account the decline in the value of money over time, assuming a discount rate of 0.06. The results are presented in Figure 8.

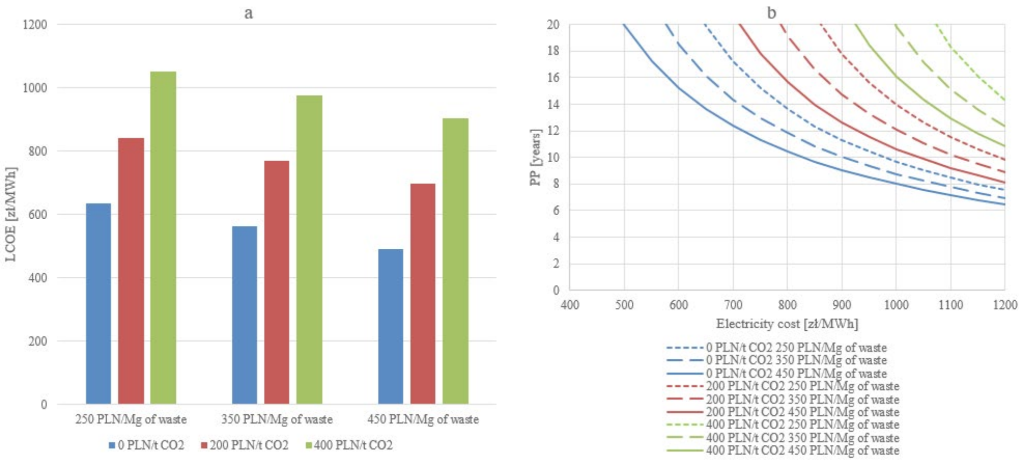

Fig. 8. Results of economic analysis
a) LCOE b) payback period

Rys. 8. Wyniki obliczeń ekonomicznych
a) LCOE b) czas zwrotu

In the case of the examined HSW, profits from waste disposal play an important role. Along with the increase in the cost of waste by PLN 200, it is possible to reduce the cost of electricity production by approximately PLN 150. For the same profits from the sale of electricity, the payback period of the installation is also much shorter. However, the return of the installation in less than ten years is possible, even at the "gate fee" of 450 PLN /Mg, only when the electricity price exceeds 800 PLN/MWh. In the options including emission fees, the price is in all cases over 1,000 PLN/MWh. In the absence of profits from waste disposal, the installation would not be profitable.

The LCOE of the system is much higher than the LCOE of PV (138 USD/MWh in Germany) and wind sources (less than 100 USD/MWh in Germany) (IRENA 2020). However, in context of hybrid energy systems in Poland, it would not be as expensive. It would be cheaper than a PV -battery system (314–455 \$/MWh) (Małkowski et al. 2020) or comparable with a solar-wind system (270–510 €/MWh) (Palej et al. 2019). Solar-wind HSW with storage LCOE are even higher (Kasprzyk et al. 2020). The costs of electricity in previous research (Bagheri et al. 2018) are similar to those achieved in this paper (more than 300 \$/MWh). However, it should be noted that the battery is used in that research which increases costs.

Conclusions

The paper proves that the municipal waste gasification installation can be used in hybrid generation systems for balancing the electricity generation and the demand. The production of syngas enables the storage of energy that can be used in periods of increased demand or reduced generation from RES. However, due to the inertia of the gasification process, it is not possible to work as an EES, as it would require very frequent start-ups and shutdowns of the installation. As a result, a surplus generation from RES was created, which was limited in the calculations. This results in a small capacity factor of RES (especially of PV sources). For this reason, the analyzed system would cover only about 54.5% of the demand of the analyzed consumer. If additional EESs were used, it would be possible to reduce the dependence on power from the grid. However, such a system already guarantees the possibility of controlling the generation and equalizing it with the demand.

The net efficiency of the municipal waste gasification system is only 16.7%. This is due to the necessity to consume energy to compress the synthesis gas before storage. Moreover, the turbines run most of the time at less than the nominal power, which also reduces efficiency. Due to this, CO2 emissions from such a system would be very high. Each MWh of electricity generated would emit more than 1 t of CO_2.

The investment costs for the analyzed system are very high. This is due to the fact that the time of use of individual sources is low, which increases the costs in relation to the production of electricity. However, HSW can be economically viable by taking into account waste disposal fees. Both the energy cost and the payback time of the installation depend on the amount of gate fees and possible emission charges. If ITPOK is introduced to the EU ETS, the profitability of such HSW would drop dramatically due to the very high emission per electricity generation.

The analysis does not take into account the changing composition of the fuel, which affects the gasification process and the quality of the synthesis gas. However, by using a waste over -sieve fraction, the impact of these changes would be limited. Other limitations of the research include only considering the steady-state of all components and not taking the ramp-rate capacity of a gas turbine into account. Due to the lack of data, author did not take into consideration the unearthing cost of the HSW. All of these limitations should examined in future research projects.

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Wstępna analiza techniczno-ekonomiczna potencjału wykorzystania instalacji zgazowania odpadów komunalnych w hybrydowym systemie wytwarzania energii elektrycznej

Streszczenie

W artykule przedstawiono wyniki modelowania i analizy hybrydowego systemu wytwórczego (HSW), zawierającego instalację zgazowania odpadów komunalnych, współpracującego z siecią elektroenergetyczną. Zamodelowano HSW składający się z farmy wiatrowej, farmy PV i instalacji zgazowania. System ten służy do zasilania odbiorcy komunalnego o maksymalnym zapotrzebowaniu na moc równym 10 MW i rocznym poborze energii elektrycznej 42,351 GWh. Generację w źródłach odnawialnych obliczono na podstawie danych meteorologicznych. Ponadto, w celu wyrównywania generacji HSW z zapotrzebowaniem na moc odbiorców zastosowano magazyn gazu. Przedstawiono trzystopniowy model generatora gazu. Poddano go walidacji, a następnie obliczono jego sprawność oraz skład generowanego gazu. Dokonano analizy energetycznej oraz ekonomicznej badanego HSW. Wyznaczono czas pracy poszczególnych źródeł, ich sprawności, a także generację energii elektrycznej netto i brutto całego HSW. W analizie uwzględniono pobór energii elektrycznej na potrzeby własne. Analizowany HSW pokrywał 54,5% zapotrzebowania. Większość (30,2%) pokrywała instalacja zgazowania. Charakteryzowała się ona niską sprawnością netto równą 16,7%. Przedstawiono przebiegi czasowe generacji w źródłach oraz wykres napełnienia magazynu gazu. W części ekonomicznej zaprezentowano na wykresach wyniki obliczeń wartości bieżącej netto oraz okresu zwrotu instalacji w celu sprawdzenia opłacalności systemu. Koszt wytwarzania energii elektrycznej wyniósł 490–1050 zł/MWh. Wyniki wskazują, że zgazowanie odpadów komunalnych jest możliwe do zastosowania jako część HSW w celu wyrównania generacji z zapotrzebowaniem. Ponadto, zastosowanie takiego układu jest opłacalne ekonomicznie. Jednakże, system zgazowania charakteryzuje się wysoką emisją CO_2 oraz niską sprawnością.

Słowa kluczowe: hybrydowy system wytwórczy, zgazowanie odpadów komunalnych, koszty wytwarzania energii, modelowanie systemów wytwórczych