

Scenario-Based Assessment of Climate Neutrality Pathways in Pałecznica Municipality, Poland

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This document presents an assessment of future energy demand and CO₂ emissions in Pałecznica municipality up to 2050, using a scenario-based modelling approach. The analysis covers major sectors, including buildings, transport, public infrastructure and waste management, and evaluates the impacts of selected policy measures on energy consumption, fuel structure, and emissions.

The analysed scenario assumes a modest economic development and a slight population decrease (-0,48 % per year), which leads to relatively stable or slowly decrease demand in several sectors. In this scenario, decarbonisation is primarily achieved through energy efficiency improvements, demand reduction, behavioural measures, and integrated sectoral policies. The document highlights the trade-offs between energy demand reduction and technology-led decarbonisation, and provides insights into how different policy choices can shape Pałecznica's long-term energy system and climate outcomes.

NB! The simulations were conducted solely for exploratory and analytical purposes. They do not represent official projections, nor have they been adopted or endorsed by Pałecznica municipality. Rather, these exercises serve as a basis for discussion and reflection among municipal stakeholders and may support future decision-making processes.

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1. MUNICIPALITY BUILDINGS

Energy consumption in municipal buildings refers to the amount of energy used by public facilities owned or managed by local governments, including city halls, schools, libraries, police and fire stations, public works facilities, and recreational centers. These buildings often have diverse functions and require energy for lighting, heating, cooling, water heating, and running various equipment and systems.

1.1. Current situation

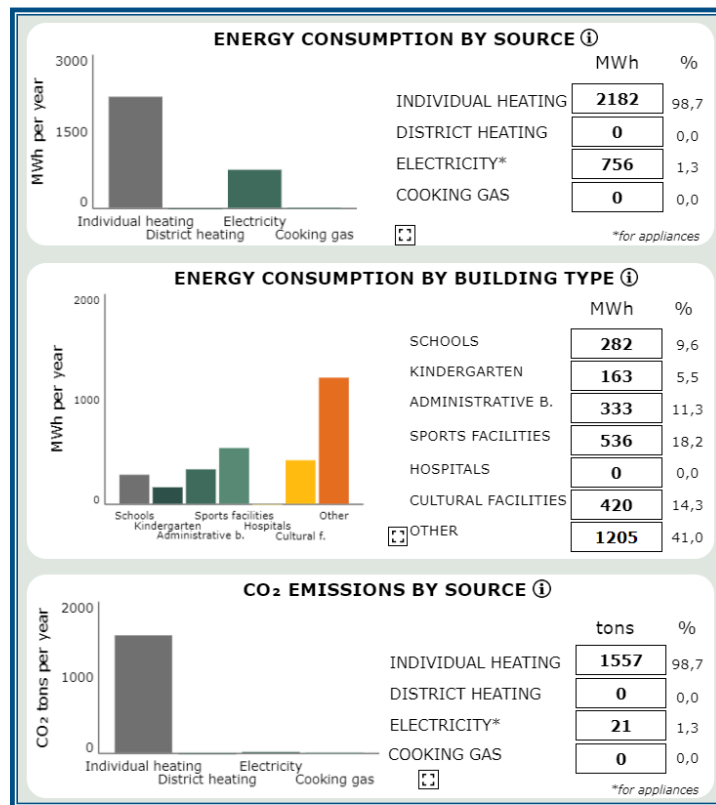
In Pałecznica municipality, the total area of municipal buildings in the baseline year is 14 388 m². The largest share by area is made up of sports and cultural facilities, schools and other building groups. The total energy consumption in municipal buildings in 2021 was 2329 MWh, which accounted for 4,8 % of energy consumption in Pałecznica municipality.

By 2050 an additional 740 m² of municipal buildings is expected to be constructed, thus increasing energy consumption by 111 MWh (4,7 %).

In energy consumption, the largest share is individual heating with 98,7 % of the total energy consumption, followed by electricity consumption for appliances (1,3 %). It should be noted that electricity for appliances does not include electricity used for heating, rather it is included in individual heating.

The average specific heat energy consumption in municipal buildings is 144 kWh/m²/year and electricity consumption is 50 kWh/m²/year (weighted average across the entire building stock).

Total CO₂ emissions in municipal buildings related to energy use in the Baseline year were 1506 tons of CO₂. The largest source of CO₂ emissions is individual heating (98,7 %), followed by electricity consumption for appliances (1,3 %). Due to the aforementioned construction of administrative buildings, emissions are expected to rise by 61 tCO₂/year (4,8 %) by 2050. Overall, CO₂ emissions in municipal buildings make up 6,6 % of total CO₂ emissions in the municipality.



1.2. Policies

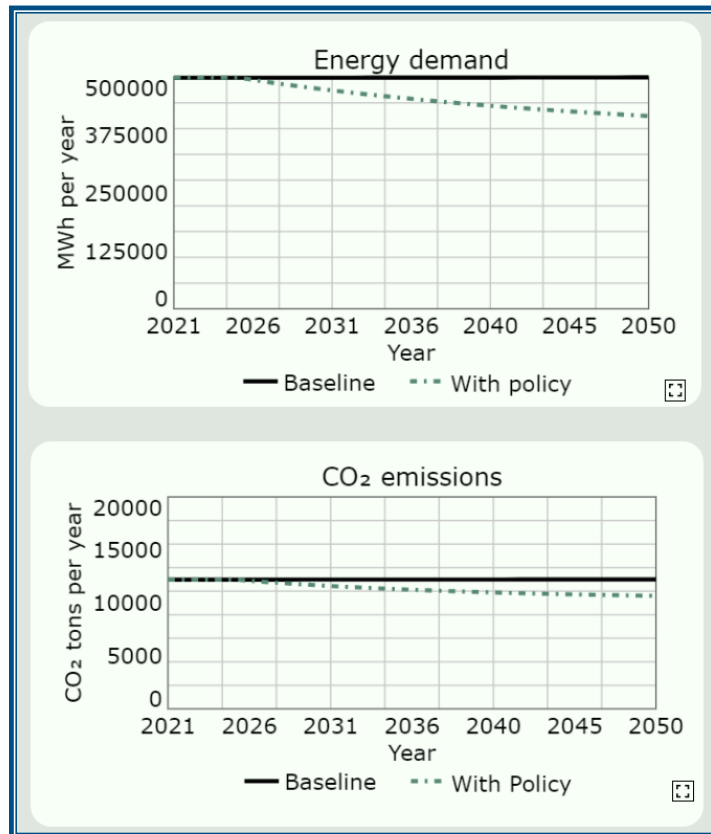
In the municipality buildings sector, several policy measures were proposed:

- **Replacement of light bulbs** (*Implementation speed (IS) 100 %/year , Expected savings (ES) 80 %*)
- **Ventilation optimization** (*IS 5 %/year, ES 10 %*)
- **RES-E generation** (*Solar photovoltaics installed capacity 1 kW*)

For all policies the implementation start year was 2025, while implementation end year was 2050.

In total, the selected policies increased the energy demand in municipal buildings by 635 MWh/year. However, 59 tCO₂ in emission savings were achieved in 2050 compared to the baseline scenario (13,8 % reduction). Additionally, the RES-E policy introduced 1 MWh/year of renewable energy in the policy scenario.

After the policy implementation start year in 2025, both energy consumption and emissions continue to decrease in a relatively constant rate of around 3296,7 MWh/year (~0,7 %) and 61,2 tCO₂/year (~0,5 %) respectively.



2. RESIDENTIAL BUILDINGS

Energy consumption in residential buildings refers to the total amount of energy used for various activities, including heating, cooling, lighting, cooking, and powering appliances. All residential building stock is grouped according to four types – single family detached, single-family attached, large multi-family, and other.

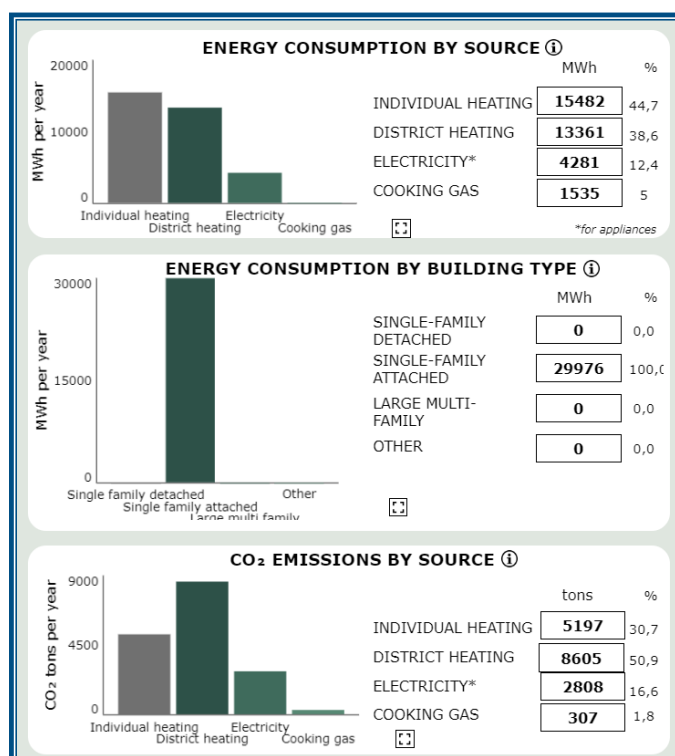
2.1. Current situation

In Pałecznica municipality, the total area of residential buildings in the baseline year is 113 200 m². This area is made up of single-family attached houses. In 2021, the total energy consumption in residential buildings was 34 281 MWh, accounting for 67,5 % of total energy consumption in Pałecznica municipality. Of the total energy consumption, district heating systems make up 38,6 % or 13 361 MWh and energy for individual heating – 44,7 % of total energy demand. Electricity consumption for appliances makes up 12,4 % or 4281 MWh. It should be noted that electricity for appliances does not include electricity used for heating, rather it is included in individual heating.

By 2030 an additional 2500 m² of single-family attached houses is expected to be constructed, thus increasing energy consumption by 379 MWh (1,1 %).

The average specific energy consumption for space heating and hot water preparation in the residential sector is 222 kWh/m²/year per year, and electricity consumption is 37 kWh/m²/year (weighted average across the entire building stock).

The amount of CO₂ generated in the household sector in the Baseline year were 16 729 tCO₂/year, which is 71,1 % of the municipality's CO₂ emissions. Due to the aforementioned construction of residential buildings, emissions are expected to rise by 188 tCO₂/year (1,1 %) by 2050. The largest source of CO₂ emissions in residential buildings is district heating, which is responsible for 50,9 % of total CO₂ emissions followed by individual heating (30,7 %).



2.2. Policies

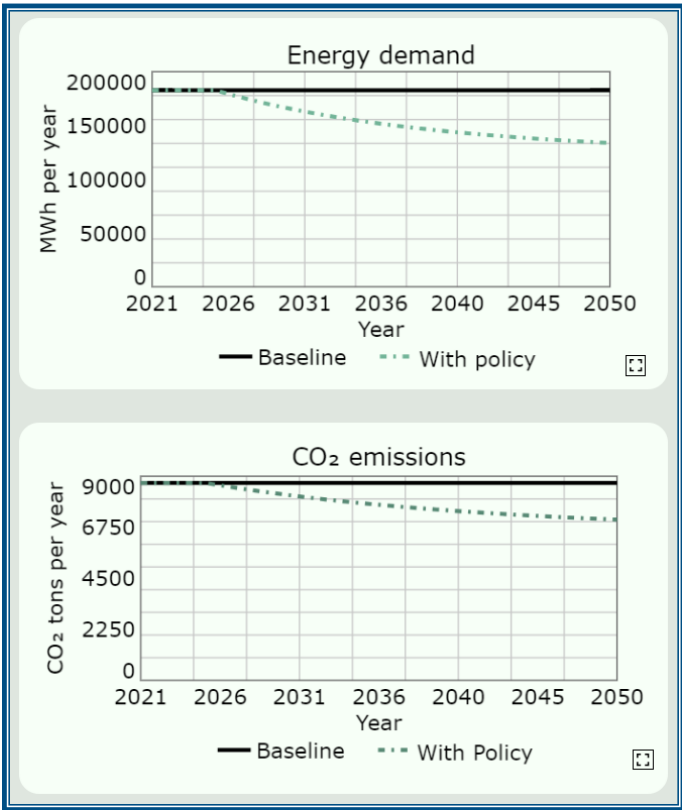
To reduce energy consumption and emissions, a comprehensive renovation strategy in single-family houses was tested, starting in 2025.

- **Renovation of single-family houses (IS 3 %/year, ES 10 %)**

The policy implementation start year was 2025, while implementation end year was 2050.

In total, the selected policy achieved 1524 MWh in energy savings and 729 tCO₂ in emission savings in 2050 compared to the baseline scenario (4,4 % and 4,3 % reductions respectively).

After the policy implementation start year in 2025, both energy consumption and emissions continue to decrease in a relatively constant rate of around ~0,19 % and ~0,13 % respectively.



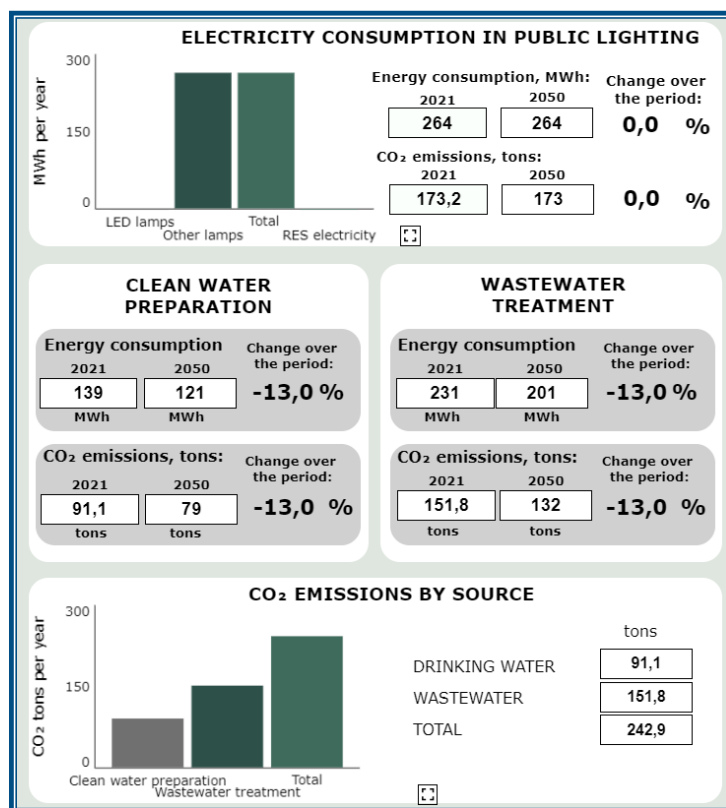
3. PUBLIC INFRASTRUCTURE

The Public Infrastructure sector encompasses essential services and systems that support communities and contribute to their quality of life. This sector includes electricity consumption related to public lighting, clean water preparation, and wastewater treatment, all of which are critical to maintaining public health, safety, and urban functionality.

3.1. Current situation

In Pałecznicza municipality, the expected total electricity consumption in the Public infrastructure sector in the baseline year is 634 MWh/year, which is 4,8 % of the municipality’s total energy consumption. Due to constant population decrease, the amount energy used for clean water preparation and wastewater treatment is expected to decrease by 13 %, bringing the total energy consumption of the sector to 586 MWh per year in 2050; with public lighting accounting for 45,1 %, wastewater treatment – 34,3 % – and drinking water preparation – 20,6 % of the total energy consumption.

The amount of CO₂ generated in the Public Infrastructure sector in the baseline year is 416,1 tons/year and it is expected to decrease to 384 tons/year (7,7 % reduction) in 2050 due to population decrease.



3.2. Policies

In this sector, no policy measures were proposed or tested, as the municipality has currently no plans to implement additional interventions. Therefore, the baseline scenario remains unchanged, and no simulated energy or emission reductions are projected for this sector.

This decision may reflect limited municipal influence, lack of cost-effective measures, or prioritization of other sectors with higher reduction potential.

4. OTHER SECTORS

In Other sectors, energy consumption from four sub-sectors is considered: Commercial and Tertiary, Industry and Construction, Agriculture and Forestry, and Other. Only emissions related to energy consumption are considered in this sector. The calculations are based on aggregated statistical data on energy consumption in sectors and assumptions about future development trends.

4.1. Current situation

In Pałecznica municipality, Other sectors energy consumption and GHG emissions are not included in the baseline inventory and projection.

4.2. Policies

In Pałecznica municipality, Other sectors energy consumption and GHG emissions were not included in the baseline inventory and projection; thus, no policy analysis was conducted.

5. TRANSPORT

The transport sector in municipalities is a significant contributor to greenhouse gas (GHG) emissions, primarily due to reliance on fossil fuels. Sectors covered include: municipal vehicle fleet, public and private transportation. Only land transport and CO₂ emissions related to fuel combustion are considered. It should be noted that the results for the transport sector are obtained through calculations, not based on actual fuel invoices. Therefore, there may be data discrepancies.

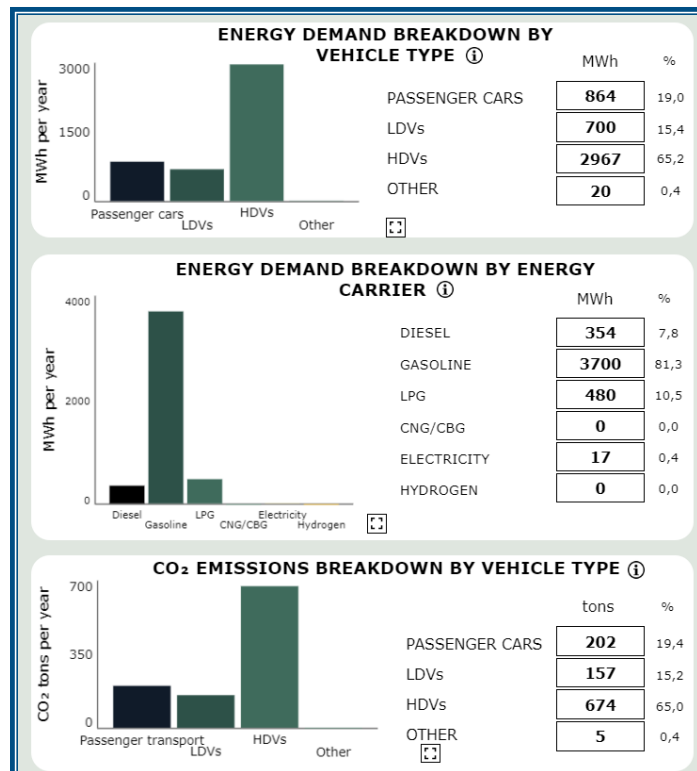
5.1. Current situation

Municipal vehicle fleet

The municipal vehicle fleet consists of 114 passenger cars, 42 LDVs, 28 HDVs un 6 other vehicles. Assuming the average annual vehicle mileage, specific fuel consumption by fuel type and fuel type distribution, it was calculated that the energy consumption of the municipal vehicle fleet is 4551 MWh per year, which is equivalent to 8,9 % of the municipality's total energy consumption.

In terms of fuel consumption, gasoline accounts for the largest share (81,3 %), followed by liquefied petroleum gas (10,5 %). By vehicle type, the most significant energy consumer is HDVs (65 %), followed by passenger cars (19,4 %) and LDVs (15,2 %). Total CO₂ emissions related to the municipality's vehicle fleet amount to 1037 tons of CO₂ per year, or approximately 4,4 % of the municipality's total CO₂ emissions.

The baseline scenario does not assume any changes in the municipal vehicle fleet, thus energy consumption and emissions are assumed to remained unchanged from the base year.



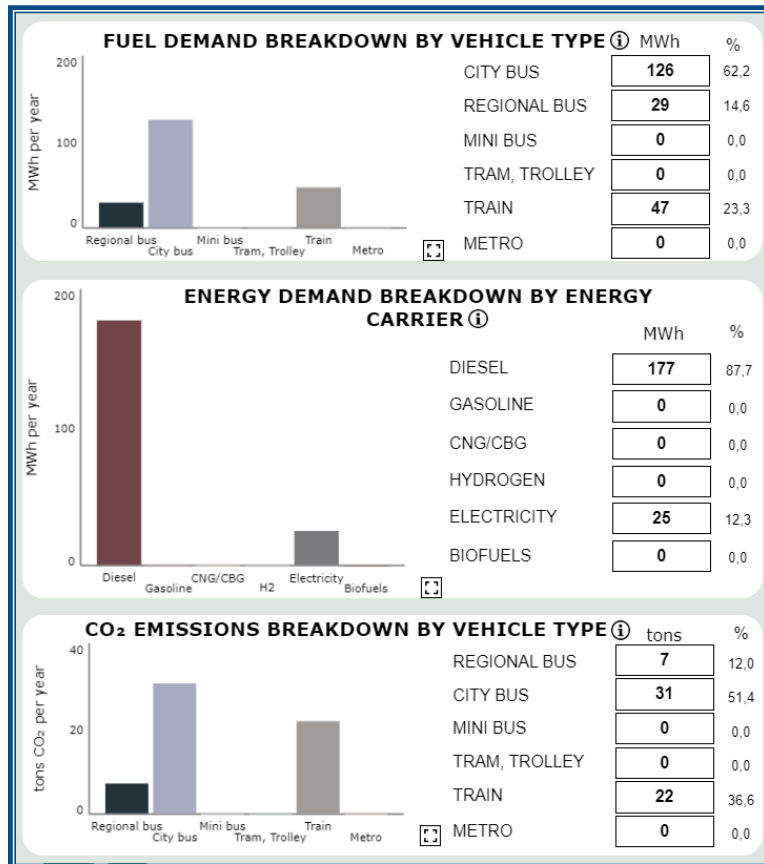
Public transport

According to existing data, 2,9 million passenger kilometres per year are performed by public transport. The largest share of this demand is made up of city public transport (79,3 %), followed by regional public transport (20,7 %).

Based on the assumptions made regarding the use of various public transport modes, average occupancy rates, average fuel consumption and type of fuel used, it has been calculated that the energy consumption of public transport is approximately 233 MWh per year in 2021 or 0,4 % of the municipality’s energy consumption. Of this, the largest share is made up of city bus (62,2 %), followed by train (23,3 %) and regional bus (14,6 %). Diesel dominates in terms of fuel consumption with 87,7 %, followed by electricity with 12,3 %. Total CO₂ emissions related to energy consumption in public transport amounted to 68 tons of CO₂ in 2021 or approximately 0,3 % of the municipality's total CO₂ emissions.

The baseline scenario assumes no changes in the public transport vehicle fleet or usage patterns, and no policy measures are applied. Changes in energy consumption are driven solely by exogenous assumptions, including a gradual decrease in population. As a result, public transport energy demand decreases over time.

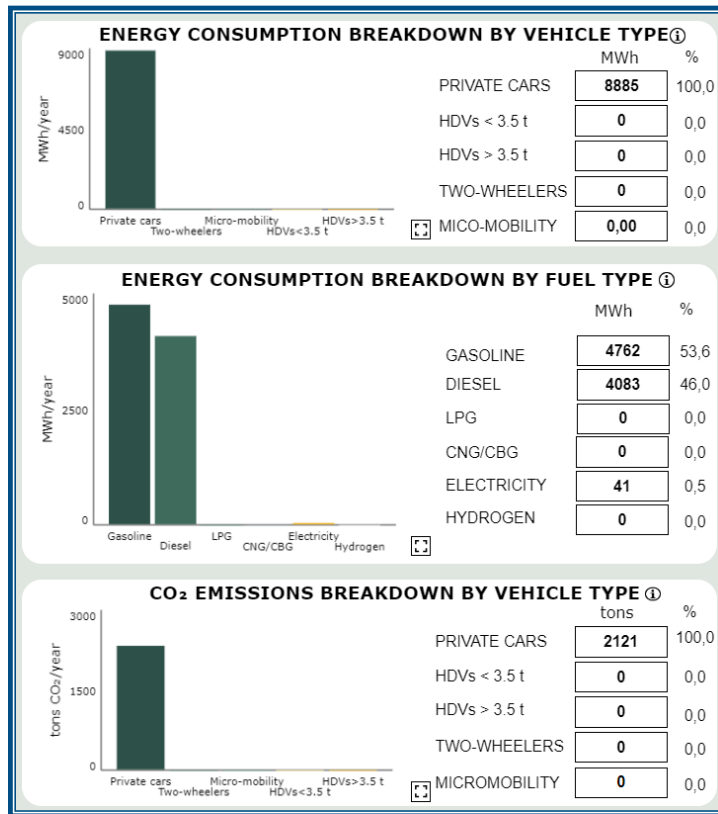
The projected energy consumption in 2050 is 202 MWh, with associated CO₂ emissions of 60 tons, corresponding to a decrease of 13 % compared to the base year.



Private transport

According to existing input data, private transport demand in the municipality is approximately 15 million passenger kilometres per year. Based on the assumptions made regarding the use of private vehicles, average fuel consumption and type of fuel used, it has been calculated that the energy consumption in the private transport sector will reach 8885 MWh per year by 2050 and reach 17,3 % of the municipality’s total energy consumption. This energy demand is completely made up by private cars. Looking at the type of fuel, the two main types of fuel are diesel (53,6 %) and gasoline (46 %). Electricity accounts for a small proportion – 41 MWh per year or 0,5 % of total energy demand. Total CO₂ emissions in the private transport sector amount to 2438 tons of CO₂ per year, or approximately 8,9 % of the municipality's total CO₂ emissions in baseline year.

The baseline scenario assumes no changes in private transport usage patterns and no policy interventions. Changes in energy consumption and emissions are driven solely by exogenous assumptions, including a gradual decrease in population. As a result, energy consumption and emissions decrease by approximately 13 % in 2050 compared to the base year.



5.2. Policies

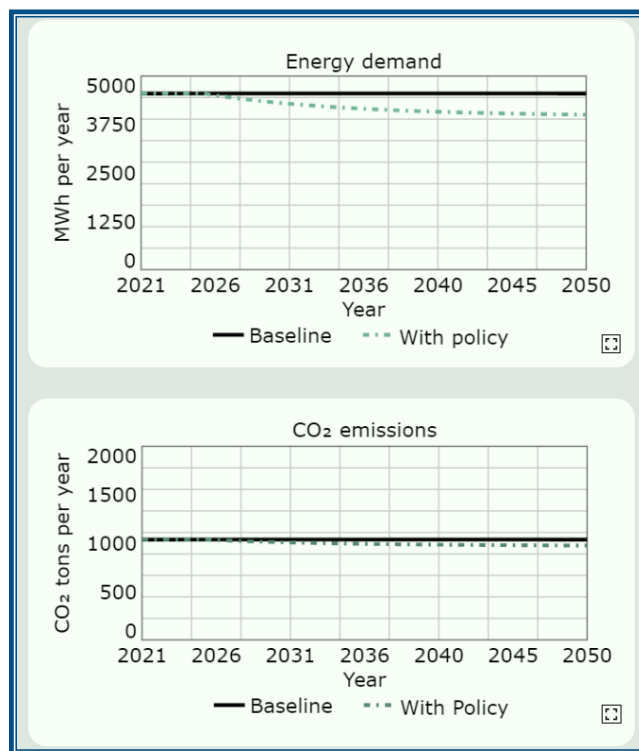
Municipal vehicle fleet

In this sector, the following policy measure was proposed:

- **Passenger car vehicle fleet decarbonization** (*Target technology choice Electric vehicles - 100 %*)

The start year for this policy was 2025, while the implementation end year was 2050.

In total, the selected policies achieved 549 MWh in energy savings and 62 tCO₂ in emission savings in 2050 compared to the baseline scenario (12,1 % and 6 % reductions respectively).



Public transport

No policy measures were introduced for public transport in the simulation. Therefore, the baseline scenario remains unchanged, with only assumed technological improvements and the effect of a decreasing population leading to a projected 13 % reduction in energy use by 2050. No additional policy-driven reductions in emissions or energy consumption were calculated.

This approach may reflect limited municipal control over public transport systems or a strategic focus on other, more impactful sectors.

Private transport

Similarly, no specific policy actions were applied in the private transport sector. As a result, projected energy consumption and CO₂ emissions follow the baseline trajectory, which includes a 13 % decrease in energy use by 2050, driven by assumed improvements in vehicle efficiency and demographic trends. No further reductions were modelled from new policy interventions.

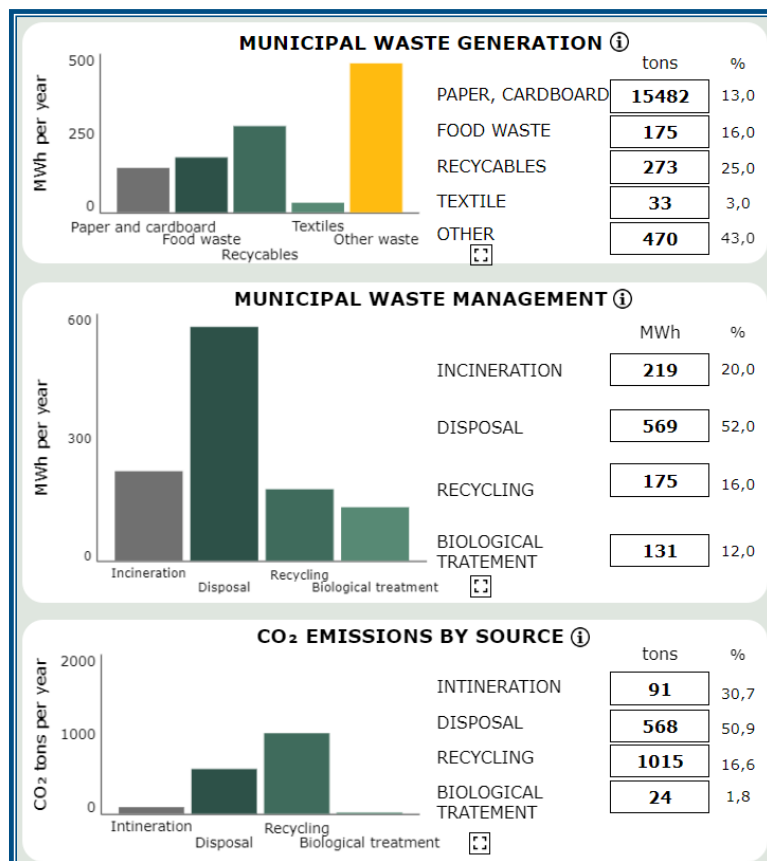
6. WASTE MANAGEMENT

In the waste management sector, GHG emissions related to waste management are considered. Effective waste management strategies, such as recycling, composting, and energy recovery, help reduce emissions by minimizing landfill waste and promoting circular economy practices. Municipalities can lower their carbon footprint by implementing sustainable waste policies, investing in waste-to-energy technologies, and encouraging community participation in waste reduction efforts.

6.1. Current situation

The calculations of the baseline scenario are based on assumptions about the number of inhabitants, the amount of waste generated per inhabitant (357 kg/capita/year) and the structure of municipal waste. Based on these assumptions, the amount of municipal waste generated in Pałecznica municipality in the base year is 1257 tons and the GHG emissions related to waste management constitute 1952 tons CO₂eq. The waste management sector accounts for approximately 7,1 % of the municipality's emissions

As the baseline scenario assumes an annual 0,48 % decrease in the municipality's population, by 2050, the total amount of waste generated and GHG emissions are expected to decrease by approximately 13 %, reaching 1094 tons of generated waste or 1697 tons CO₂eq, respectively.



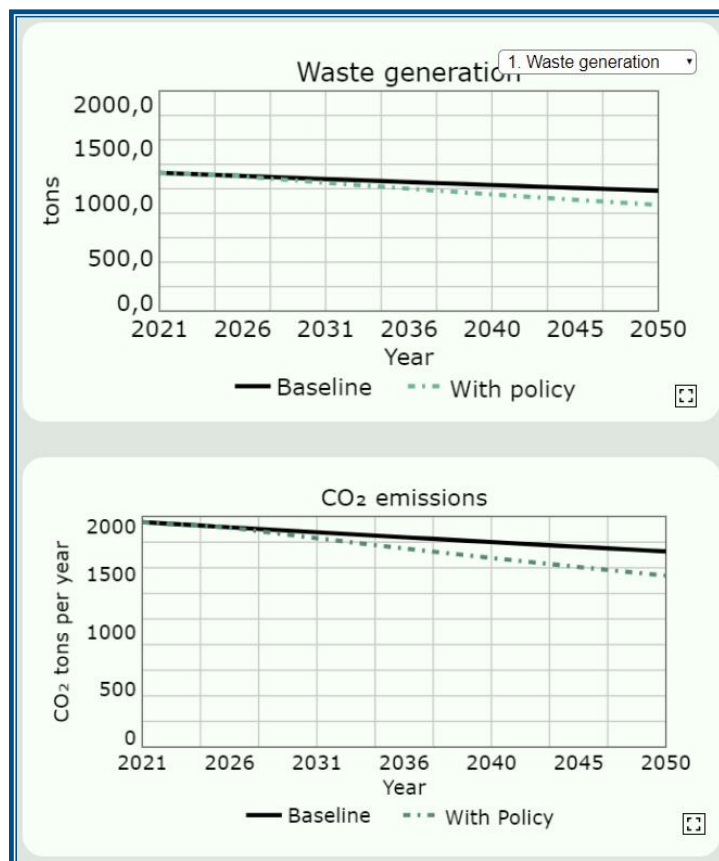
6.2. Policies

To assess the potential for further reduction of emissions, two waste-related policies were tested:

- **Reducing amount of waste generated** (IS 0,5 %/year)
- **Reducing the amount of waste landfilled** (Target share – Disposal 38 % (-14 %), Incineration 20 %, Recycling 30 % (+14 %), Biological treatment 12 %)

The start year for both policies was 2025, while the end year was 2050.

In total, the selected policy reduced the amount of waste generated by 128,6 tons and achieved 209 tCO₂eq in emission savings in 2050 compared to the baseline scenario (11,8 % and 12,4 % reductions respectively).



7. LOCAL ENERGY PRODUCTION

The Local Energy Production Sector encompasses energy production technologies and their associated environmental impact. This sector includes local electricity and heat generation parameters. The municipality can reduce CO₂ emissions in this sector by reducing heat losses in the system, recovering lost heat and decarbonizing various energy systems.

NB! The local energy production sector differs from other sectors in that it represents energy supply rather than energy demand. The 2050 scenario without energy-production-specific policies therefore reflects the energy demand generated by all other sectors after their respective policies are applied, but before any policies targeting local energy production are introduced.

7.1. Current situation

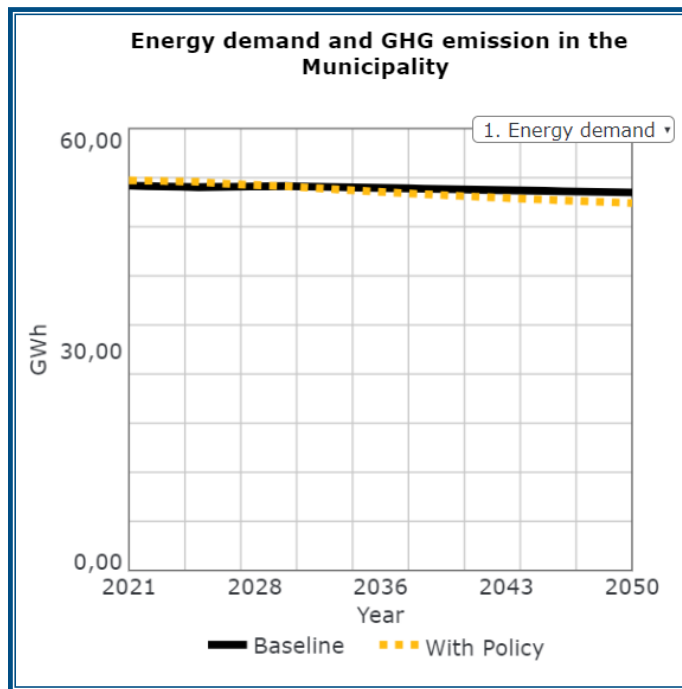
In Pałecznica municipality, Local energy production energy demand and GHG emissions are not included in the baseline inventory and projection.

7.2. Policies

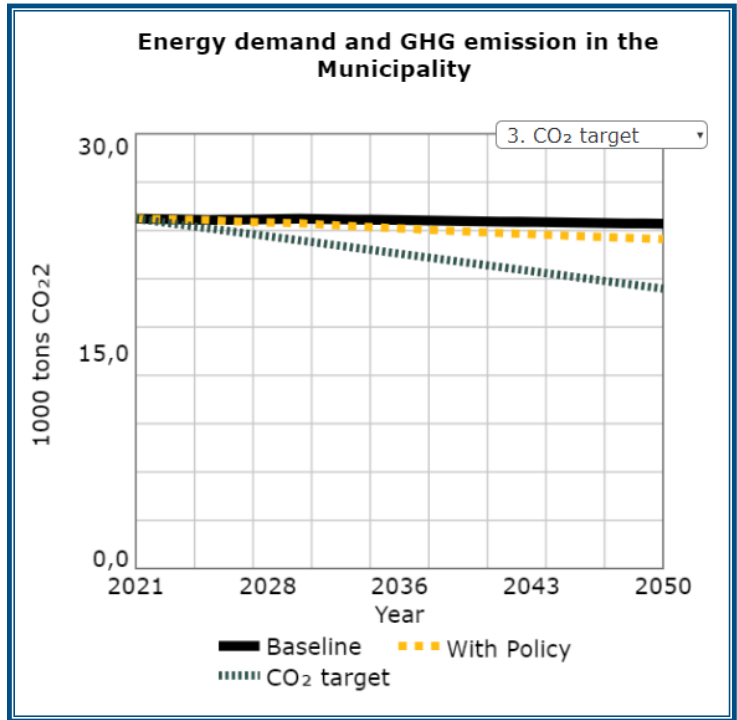
In Pałecznica municipality, Local energy production energy demand and GHG emissions were not included in the baseline inventory and projection; thus, no policy analysis was conducted.

8. RESULT OVERVIEW

The results of the simulation show that in the baseline scenario energy demand in the municipality decreases from 52,24 GWh in the baseline year to 51,32 GWh in 2050 due to a dwindling population. As illustrated in the figure below, the implementation of the selected policy package causes a gradual energy demand decrease, resulting in an energy demand of 49,89 GWh by 2050. This corresponds to energy savings of approximately 1437,1 MWh, or 2,8 % compared to the baseline projection.



The selected policy package leads to similarly modest emission reductions – CO₂ emissions decrease from 23,8 thousand tons in the baseline scenario to approximately 22,7 thousand tons in the policy scenario by 2050, resulting in annual emission savings of 1060,4 tons (4,5 %). As shown in the figure below, while the policy scenario slightly lowers emissions compared to the baseline trajectory, emissions remain above the long-term CO₂ target (20 % reduction by 2050), indicating that additional mitigation measures would be required to fully achieve the municipality's climate objectives.



9. CONCLUSIONS

The results of the scenario analysis for Pałecznicza municipality indicate that the implementation of the selected policy package leads to very limited reductions in both energy demand and greenhouse gas emissions by 2050, primarily due to the narrow scope of applied measures and the absence of structural changes in key sectors.

Overall, total energy demand decreases by approximately 2,8 % (1 437 MWh) compared to the baseline scenario, while CO₂ emissions are reduced by 4,5 % (1 060 tCO₂). These modest reductions reflect both the relatively low ambition of the selected policies and the fact that the baseline scenario already assumes a gradual decrease in demand due to declining population.

The results show that **the residential buildings sector** is the dominant contributor to energy consumption and emissions, accounting for approximately 67,5 % of total energy demand and over 70 % of emissions. However, the implemented renovation policy achieves only 4,4 % energy savings and 4,3 % emission reductions, indicating that significantly deeper renovation rates or additional measures—such as heating system decarbonisation—would be required to achieve substantial impact.

In **the municipal buildings sector**, policies result in emission reductions of 59 tCO₂ (13,8 %), despite an overall increase in energy demand. This increase is likely associated with additional building construction and the interaction of implemented measures. The results highlight that isolated efficiency measures without addressing heating systems provide limited overall benefits.

The transport sector contributes only marginally to emission reductions. While the decarbonisation of the municipal fleet results in 12,1 % energy savings and 6 % emission reductions, no measures are applied to private transport, which limits the overall impact of the sector. Given that transport still contributes to total emissions, this represents a significant untapped potential.

In **the public infrastructure sector**, no policy measures were implemented, and reductions are driven solely by demographic trends. Similarly, other sectors and local energy production are not included in the analysis, which further constrains the overall reduction potential.

The waste management sector shows moderate improvements, achieving 12,4 % emission reductions, mainly due to waste reduction and improved waste treatment practices. However, its contribution to total emissions remains relatively small.

Overall, the analysis demonstrates that incremental and sector-limited policies result in only marginal improvements in both energy demand and emissions. The absence of interventions in key sectors—particularly transport, municipal buildings, and energy supply—significantly limits the municipality's ability to achieve meaningful decarbonisation.

The results suggest that to move toward climate neutrality, Pałecznicza municipality would require a more comprehensive and ambitious policy package, including deep building renovation, heating system transformation, transport electrification, and broader sectoral coverage.

Table 1. Summary Table of Key Quantitative Results (2050)

| Sector | Indicator | Results |
|---|----------------------------|----------------------------------|
| Municipal buildings | Energy savings | -635 MWh (-26 %) |
| | Emission reduction | 59 tCO ₂ (3,8 %) |
| | Renewable generation | 1 MWh |
| Residential buildings | Energy savings | 1524 MWh (4,4 %) |
| | Emission reduction | 729 tCO ₂ (4,3 %) |
| | Renewable generation | – |
| Public infrastructure | Energy savings | – |
| | Emission reduction | – |
| | Renewable generation | – |
| Other sectors | Energy savings | – |
| | Emission reduction | – |
| Municipal fleet | Energy savings | 549 MWh (12,1 %) |
| | Emission reduction | 62 tCO ₂ (6 %) |
| Public transport | Energy savings | – |
| | Emission reduction | – |
| Private transport | Energy savings | – |
| | Emission reduction | – |
| Waste management | Waste generation reduction | 128,6 t (11,8 %) |
| | Emission reduction | 209 tCO ₂ eq (12,4 %) |
| Local energy production | Energy savings | – |
| | Emission reduction | – |
| | Renewable generation | – |
| Peak emissions from imported electricity | tCO ₂ | – |