



ComActivate

Enabling community action for energy sufficiency

REPORTS ON POSSIBILITIES FOR ENERGY PRODUCTION FROM RENEWABLE SOURCES NEEDED FOR ENERGY SELF SUFFICIENCY OF TARGET DISTRICTS

Assessment and calculation of potential for energy
production and required investment

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Marin Petrovic, Eko Invest d.o.o.



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Author(s)	Marin Petrovic	
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Content

EXECUTIVE SUMMARY	5
INTRODUCTION.....	6
BULGARIA, BURGAS.....	8
GENERAL INFORMATION.....	8
CHOICE OF RENEWABLE ENERGY SOURCES.....	10
PV PANELS	10
HUNGARY, BUDAPEST	16
GENERAL INFORMATION.....	16
CHOICE OF RENEWABLE ENERGY SOURCES.....	17
PV PANELS	19
LITHUANIA, ELEKTRĖNAI AND KAIŠIADORYS.....	21
GENERAL INFORMATION.....	21
CHOICE OF RENEWABLE ENERGY SOURCES.....	22
BIOMASS IN ELEKTRĖNAI.....	23
PV PANELS IN ELEKTRĖNAI AND KAIŠIADORYS	24
CONCLUSION	28

List of Figures

FIGURE 1: PART OF TARGET NEIGHBOURHOOD WITH CLOSE-PACKED SMALLER MFABs.....	8
FIGURE 2: PART OF TARGET NEIGHBOURHOOD WITH LARGE RESIDENTIAL BUILDINGS.....	8
FIGURE 3: EXAMPLES OF LARGE RESIDENTIAL BUILDINGS WITH INSTALLED AIR CONDITIONERS	9
FIGURE 4: EXAMPLE OF INFORMATION PROVIDED BY GLOBALSOLARATLAS.INFO FOR BURGAS.....	11
FIGURE 5: MONTHLY AVERAGE OUTPUT FOR INSTALLED CAPACITY OF 1 kWp FOR BURGAS	12
FIGURE 6: AVERAGE HOURLY PROFILES FOR INSTALLED CAPACITY OF 1 kWp FOR BURGAS.....	12
FIGURE 7: OVERVIEW OF TARGET NEIGHBOURHOOD AT BURGAS.SOLARCITIES.BG.....	13
FIGURE 8: EXAMPLE OF DETAILED DATA FOR RESIDENTIAL COMPLEX ВЪЗРАЖДАНЕ 2 AVAILABLE AT BURGAS.SOLARCITIES.BG	13
FIGURE 9: EXAMPLE OF DETAILED PV PANEL POSITIONING DATA IN THE PROJECT	14
FIGURE 10: SCHEME OF PV PANEL CONNECTION WITH ELECTRICAL GRID IN THE PROJECT	14
FIGURE 11: THE EXAMPLE OF ELECTRICITY BALANCE FOR RESIDENTIAL COMPLEX ВЪЗРАЖДАНЕ 2.....	15
FIGURE 12: PART OF TARGET NEIGHBOURHOOD WITH CLOSE-PACKED SMALLER MFABs WITH INNER YARDS	16
FIGURE 13: PART OF TARGET NEIGHBOURHOOD WITH LARGE RESIDENTIAL BUILDINGS AND HIGH-RISES.....	16
FIGURE 14: EXAMPLE OF INFORMATION PROVIDED FOR BUDAPEST	19
FIGURE 15: PART OF TARGET NEIGHBOURHOOD IN ELEKTRĖNAI.....	21
FIGURE 16: PART OF TARGET NEIGHBOURHOOD IN KAIŠIADORYS	21
FIGURE 17: EXAMPLE OF INFORMATION PROVIDED BY GLOBALSOLARATLAS.INFO FOR ELEKTRĖNAI	24
FIGURE 18: EXAMPLE OF INFORMATION PROVIDED BY GLOBALSOLARATLAS.INFO FOR KAIŠIADORYS	25
FIGURE 19: MONTHLY AVERAGE OUTPUT FOR INSTALLED CAPACITY OF 1 kWp FOR ELEKTRĖNAI	25

FIGURE 20: MONTHLY AVERAGE OUTPUT FOR INSTALLED CAPACITY OF 1 kWp FOR KAIŠIADORYS	26
FIGURE 21: AVERAGE HOURLY PROFILES FOR INSTALLED CAPACITY OF 1 kWp FOR ELEKTRĖNAI	26
FIGURE 22: AVERAGE HOURLY PROFILES FOR INSTALLED CAPACITY OF 1 kWp FOR KAIŠIADORYS	26

List of tables

TABLE 1: AVERAGE PRECIPITATION DAYS AND MEAN MONTHLY SUNSHINE HOURS FOR BURGAS	9
TABLE 2: OVERVIEW OF ENERGY NEEDS AND SAVINGS FOR BURGAS' NEIGHBOURHOOD	11
TABLE 3: SPECIFIC VALUES OF KEY PARAMETERS YIELDED FROM 25 BUILDINGS HAVING DETAILED PROJECTS	14
TABLE 4: KEY VALUES AT THE LEVEL OF THE ENTIRE NEIGHBOURHOOD	14
TABLE 5: ADJUSTED KEY VALUES AT THE LEVEL OF THE ENTIRE NEIGHBOURHOOD	15
TABLE 6: AVERAGE PRECIPITATION DAYS AND MEAN MONTHLY SUNSHINE HOURS FOR BUDAPEST	17
TABLE 7: OVERVIEW OF ENERGY NEEDS AND SAVINGS FOR BURGAS' NEIGHBOURHOOD	19
TABLE 8: SPECIFIC VALUES OF KEY PARAMETERS YIELDED FROM 30 BUILDINGS	20
TABLE 9: KEY VALUES AT THE LEVEL OF THE ENTIRE NEIGHBOURHOOD	20
TABLE 10: AVERAGE PRECIPITATION DAYS AND MEAN MONTHLY SUNSHINE HOURS FOR ELEKTRĖNAI AND KAIŠIADORYS	22
TABLE 11: KEY PARAMETERS FOR PV PANELS IN ELEKTRĖNAI	27
TABLE 12: KEY PARAMETERS FOR PV PANELS IN KAIŠIADORYS	27

Executive Summary

The ComActivate project focuses on reducing energy poverty for people living in multi-family apartment buildings (MFABs) in four pilot municipalities in Bulgaria, Hungary and Lithuania, among other, through the development of Neighbourhood Energy Sufficiency Roadmaps (NESR).

This report provides analysis of possibility of covering energy needs in four target municipalities from renewable sources available and preferred at their locations, in order to achieve neighbourhoods' energy self-sufficiency. The analysis is done separately for each municipality, as they prefer different renewable energy sources, and includes estimation of required investment.

Together with other project tasks and reports, this report will help demonstration sites develop approaches to reduce energy poverty in MFABs. The aim of this analysis is to enable relevant authorities to establish efficient and effective policy & finance mechanisms enabling large-scale investments in residential sector of final energy consumption. Each analysis will serve as a reliable planning tool, enabling local authorities to get clear insight in entire residential stock on their territory and scope of pertaining energy-saving and emission-reduction needs and opportunities.



Introduction

The European Green Deal aims at reducing carbon emissions by at least 55% by 2030 compared to 1990. The building sector plays a crucial role in achieving this goal because it is responsible for 35% of energy-related greenhouse gas emissions¹ and 43% of energy consumption² in Europe. This calls for interventions at building and neighbourhood level which will minimise the absolute energy consumption and green the leftover energy used, to reduce related greenhouse gas emissions. In addition, more than 10% of citizens in the EU are categorised as energy poor.³ Tackling energy poverty can include change of (collective) behaviour patterns of occupants, improvement of energy performance of the building, or increasing local green energy production to reduce energy bill costs.

Interventions can target single buildings and its occupants. This might be a renovation, ideally using low carbon materials (e.g. secondary materials, easily recyclable elements), changes of occupants' energy consumption user patterns, and of course the installation of renewable energy technologies at single building level. Another approach targets many buildings on a neighbourhood level (also referred to as district approach). The neighbourhood approach for tackling energy poverty and climate targets for a city goes beyond the named interventions, such as renovations, of just an array of single buildings. It considers indicators that concern the whole geographical urban area with its building stock, green infrastructure and people. Benefits of considering the entire neighbourhood include achieving economies of scale and thus cost-efficiency (e.g. prefabricated renovation elements, sourcing building materials from a close geographical area), tackling social cohesion, sharing energy among buildings with diverging user patterns (e.g. schools and residential houses) and thus profiting from cheap electricity rates, and the possibility to profit from systemic solutions such as district heating. Therefore, interventions for absolute energy reduction in buildings at neighbourhood level are more holistic and integrated and allow to harvest synergies of various social and environmental policy goals.

The European Commission identified the benefits of the neighbourhood approach and its potential, specifically to accelerate renovation rates to increase the energy performance of the building stock and at the same time to reduce carbon emissions in the building sector already in the early 2000s. On the EU level it was considered and mentioned in the Leipzig Charta⁴ and the Renovation Wave⁵ strategy and was also recognised in the 2024 recast of the EPBD⁶ under mandatory indicators of the National Building Renovation Plan requirements for member states.

Member States interpret the concept of the neighbourhood renovation approach differently. Whereas in the Western EU countries multiple instruments to roll out the neighbourhood approach were implemented, in EU countries that joined after 2004 the building sector in general was not targeted in the first place.

ComActivate project (2023-2026) is interested in neighbourhood concepts to address the energy poverty in three pilot countries, namely Bulgaria, Hungary and Lithuania, with differing climate, legal, administrative and overall cultural circumstances. In pilot districts in Burgas (BG), Budapest-Józsefváros (HU), Kaišiadorys (LT) and Elektrėnai (LT) neighbourhood energy sufficiency roadmaps (NESR) will be developed. Within those, the neighbourhood approach is specifically explored to achieve energy poverty alleviation through renovations.

This report provides analysis of possibility of covering energy needs in four target municipalities from renewable sources available at their locations. For each municipality, the preferred renewable energy sources are considered. As those sources are defined by municipality strategy and/or policy, the analysis is done separately for each municipality. The analysis includes estimation of required

¹ European Energy Agency (2023)

² Rousselot and Pinto Da Rocha (2021)

³ Widuto (2023). The ComAct project used the REACH project definition of energy poverty in D1.1.

⁴ Bundesministerium des Innern und für Heimat (2020)

⁵ European Commission (2020)

⁶ European Union (2024, pp. 37–38)

investment as well. The goal of this analysis is to demonstrate whether municipalities can reach energy self-sufficiency by using locally available renewables.

The analysis is based on the estimated energy demand for heating buildings after the implementation of all proposed measures, including insulation of external walls, roofs, and basements, as well as window replacement. Additionally, based on experience, a further reduction of approximately 5% in energy consumption can be anticipated due to changes in residents' behaviour, resulting from living in fully renovated buildings.

Together with other project tasks and reports, this report will help demonstration sites develop approaches to reduce energy poverty in MFABs. The aim of this analysis is to enable relevant authorities to establish efficient and effective policy & finance mechanisms enabling large-scale investments in residential sector of final energy consumption. Each analysis will serve as a reliable planning tool, enabling local authorities to get clear insight in entire residential stock on their territory and scope of pertaining energy-saving and emission-reduction needs and opportunities.

Bulgaria, Burgas

General information

Target neighbourhood in Bulgaria, part of Vazrazhdane district, is part of Burgas, measuring approximately 1.00 by 0.50 km and covering area of approximately 0.60 km². It includes 738 residential buildings, most of which are smaller multi-family apartment buildings (MFAB), closely packed side-by-side and sharing outer walls, with small inner yards or gardens and narrow streets between them. Beside such buildings, there are few dozens of large residential buildings (residential blocks) with several entrances each, separated from other buildings by parks, sport terrains and parking spaces. The following figures show two mentioned types of buildings.

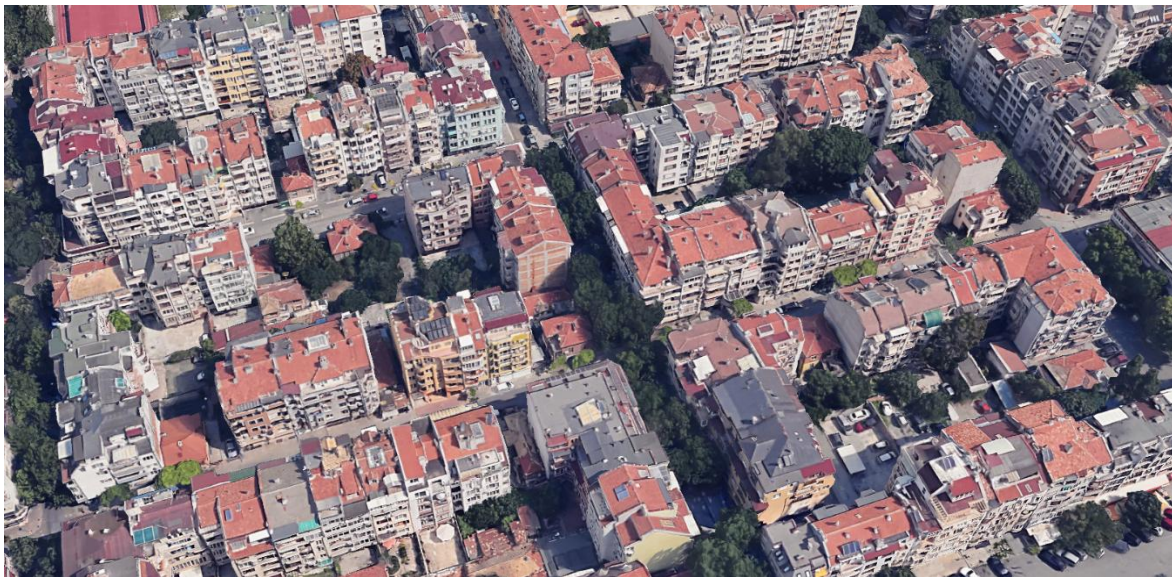


Figure 1: Part of target neighbourhood with close-packed smaller MFABs



Figure 2: Part of target neighbourhood with large residential buildings

Burgas has a humid subtropical climate. The summertime in Burgas lasts about five months from mid-May until late September. Average temperature during high season is 24 °C. Winters are milder compared with the inland part of the country, with average temperatures of 4-5 °C and below 0 °C during the night. Snow is possible in December, January, February and rarely in March; however, it can quickly melt. Table 1 below shows average precipitation days and sunshine hours for Burgas for period from 1991 to 2020. As possible to see, Burgas has relatively low number of rainy days, and a lot of sunshine.

Table 1: Average precipitation days and mean monthly sunshine hours for Burgas

	Average precipitation days	Mean monthly sunshine hours
January	8.1	76
February	7.5	110
March	8.1	147
April	9.7	207
May	9.2	278
June	9.1	302
July	6.1	339
August	4.7	323
September	5.3	264
October	6.6	185
November	9.0	118
December	9.1	63
Sum	92.6	2,412

Consequently to mild climate and hot summers, apartments and, in some cases, entire buildings are heated and cooled by using split and multi-split air conditioners. They are used to heat or cool individual rooms and spaces inside apartments, while common spaces within buildings remain without conditioning. Examples of large residential buildings with installed many air conditioners are given in figure below. For small buildings outside units are in inner yards, on terraces and balconies or, sometimes, on roofs. Several brand-new buildings are heated/cooled by using heat pumps. Energy source in all these cases is electricity, and almost all air conditioners are inverters.



Figure 3: Examples of large residential buildings with installed air conditioners

According to information collected during site visits, district heating is available, but not extensively used. The system is old, partially refurbished, and consumption is paid per energy spent, but on the building level, i.e. there are no measurements at the apartment level.

Electricity is used for lighting of residential and common spaces in buildings, as well as for preparation of domestic hot water and all appliances.

Choice of renewable energy sources

Considering climate in Burgas, particularly mean monthly sunshine hours, photovoltaic panels (PV panels) would represent excellent choice. In this way, electricity can be produced and used for heating, cooling, lighting and appliances, while the surplus can be offered at the market. There is no need for works around buildings, as installation of solar panels do not require taking space from parking lots, parks and playgrounds. Additionally, orientation of buildings is favourable, as many of them are oriented toward west and south.

Solar collectors for heating domestic hot water are also one of the possibilities, and they are seen on some of buildings in target neighbourhood. However, their retrofit installation requires significant and expensive changes in existing water distribution systems. Also, they have limited usability during winter, even vacuum ones, and have relatively complex maintenance as they are sensitive to dust and dirt.

Installing wind turbines directly on buildings would be impractical, technically complex, and ultimately costly. The added mass and vibrations could compromise the structural integrity of the buildings. Furthermore, such installations would significantly impact the architectural appearance and are generally only feasible on large buildings with flat roofs. Any meaningful economic analysis would require detailed data on potential electricity generation, which in turn depends on accurate information about wind patterns and intensity. Additionally, placement becomes problematic in areas with small, closely spaced buildings or those that share exterior walls.

Alternatively, it may be feasible to purchase (or possibly lease) a suitable area in a strategic location, construct a wind farm, and use the generated electricity to supply renewable energy to the target neighbourhood. However, evaluating this option would require consideration of legal factors at both local and state levels, complex and substantial funding requirements, and the technical challenges of building the wind farm and transmission infrastructure – all of which go beyond the scope of this report.

The installation of heat pumps would present similar challenges. Air-source heat pumps, which function similarly to air conditioners, are already commonly used as a primary source of heating during the winter. In contrast, water-source and ground-source heat pumps involve more complex systems, require greater maintenance, and come with higher installation costs. Moreover, limited space between buildings poses an additional constraint. Installing any type of heat pump system would necessitate extensive work both inside and outside the buildings, including the installation of appropriate heating elements such as fan coil units or underfloor heating systems.

Another option is to use biomass instead of the currently used natural gas. This approach would not require major modifications to the existing heating systems (piping and heating bodies) within buildings. However, it would still be necessary to install heating systems in all other buildings in the target neighbourhood and reconnect previously disconnected apartments (may require installation of piping and heating bodies). An additional challenge lies in the availability and cost of biomass, which could significantly hinder the feasibility of adopting it as a fuel source for the district heating system.

Based on what has been discussed, seen and noted during site visits, available data from literature and databases, and considering additional consultations with municipality representatives, the renewable energy source of choice for target neighbourhood in Burgas are PV panels.

PV panels

The starting point for assessment of PV panels installation are energy needs for entire neighbourhood after all proposed measures are implemented. This means that energy needs, compared with current, would be considerably lower due to heat insulation of walls, roofs and windows replacement, with numbers available from database of neighbourhood's buildingstock. As stated in introduction, it is possible to expect additional energy consumption reduction of about 3% due to behaviour change of residents. Data about energy consumption is given in Table 2.

Table 2: Overview of energy needs and savings for Burgas' neighbourhood

Buildings	-	738
Heated area	m ²	718,049
Heat required in current state of building	MWh/year	58,251
Heat required after all architectural measures	MWh/year	29,286
3% reduction due to behavioural change	MWh/year	878
Heat required after all measures	MWh/year	28,408

As possible to see, entire neighbourhood would require 28,408 MWh/year of heating energy to satisfy all heating needs (cooling is not considered). To simplify further calculations, it will be assumed that Seasonal Coefficient of Performance (SCOP) is 4, what means that for every 1 kW of electricity consumed, the unit can produce 4 kW of heating energy. This value is justified for efficient inverter-type air conditioners in Burgas climate. This further means that:

$$\text{electricity required} = \frac{\text{heat required}}{\text{SCOP}} = \frac{28,408}{4} = 7,102 \text{ MWh/year}$$

There are several ways to determine possible energy production from PV panels. The one used in this report is simplified, as detailed approach would require more input information. There is data available from web pages, e.g. globalsolaratlas.info, where all basic information are given (e.g. specific photovoltaic power output in kWh/kWp, direct normal and global horizontal irradiation in kWh/m² etc.), as shown in Figure 4.

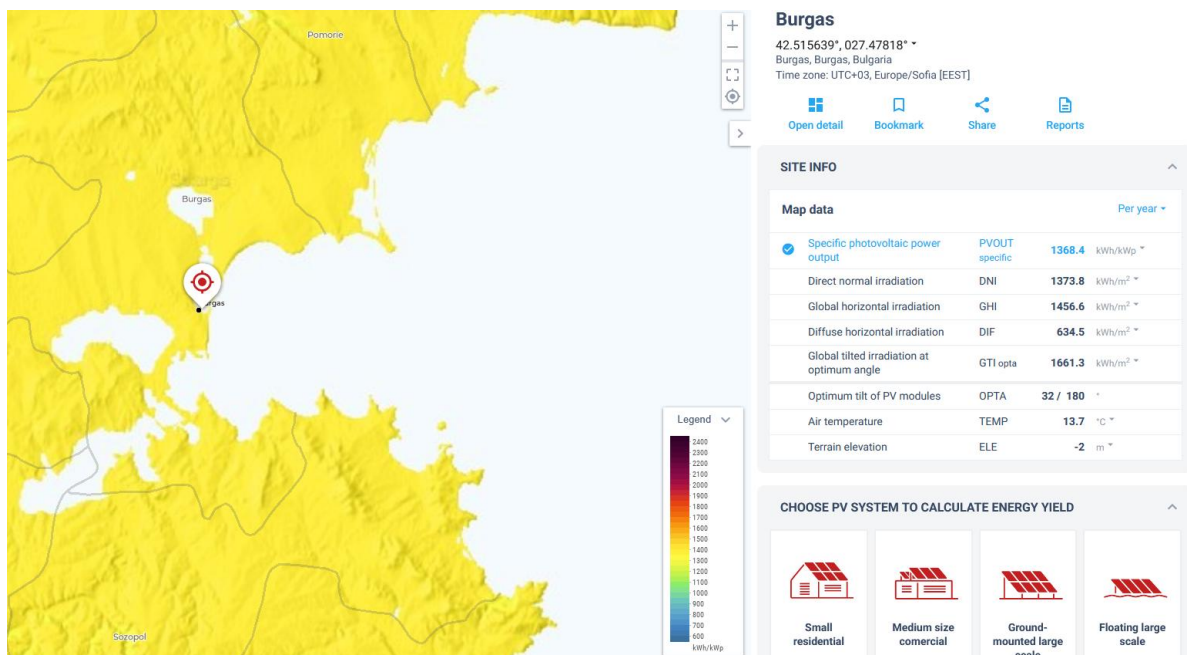


Figure 4: Example of information provided by globalsolaratlas.info for Burgas

Additionally, information on panel tilt angles, monthly average power output, and average hourly generation profiles can be obtained, as illustrated in the following figures. By default, the data is presented for 1 kWp (kilowatt peak) of installed solar capacity, though this value can be modified as needed. This data, along with other relevant inputs, is used for detailed calculations that must be performed individually for each building and then aggregated at the neighbourhood level. However, applying this approach across the number of buildings considered in this report is time-consuming.

Monthly averages

Total photovoltaic power output

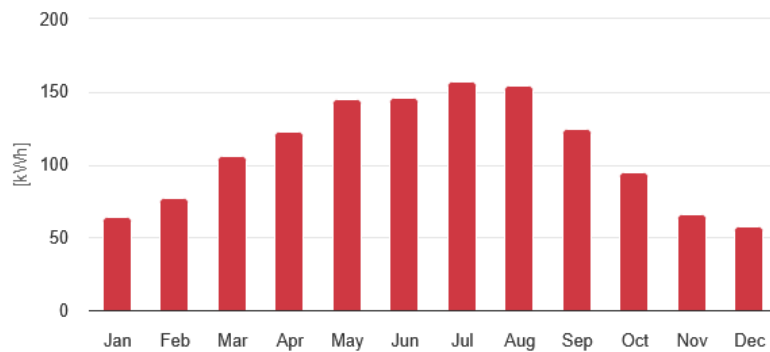


Figure 5: Monthly average output for installed capacity of 1 kWp for Burgas

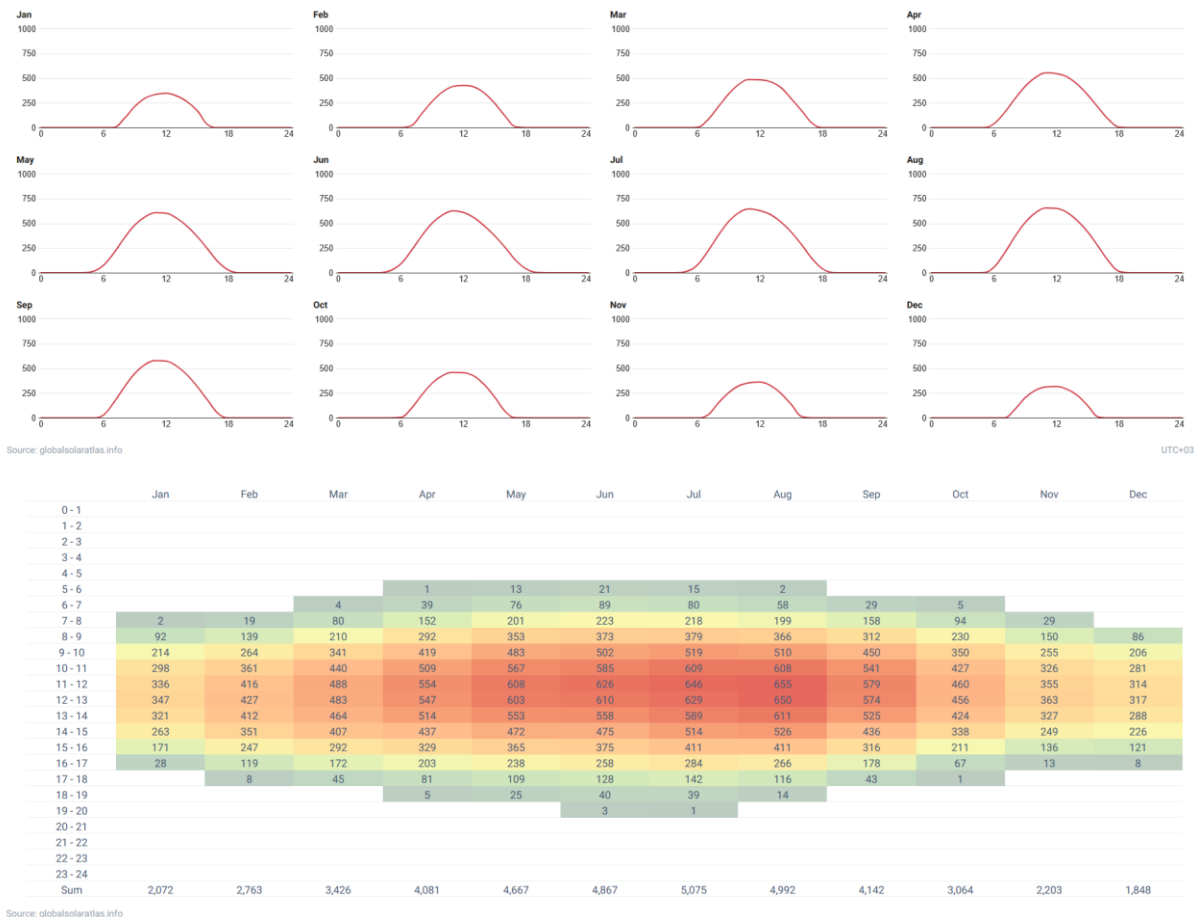


Figure 6: Average hourly profiles for installed capacity of 1 kWp for Burgas

There is another database, at burgas.solarcities.bg, where is possible to obtain data about electricity production for all residential buildings from target neighbourhood, as shown in Figure 7. There are detailed projects for 25 buildings (marked blue), covering calculations, technical documentation and estimated costs, while for the rest only estimated values of electricity production are given.

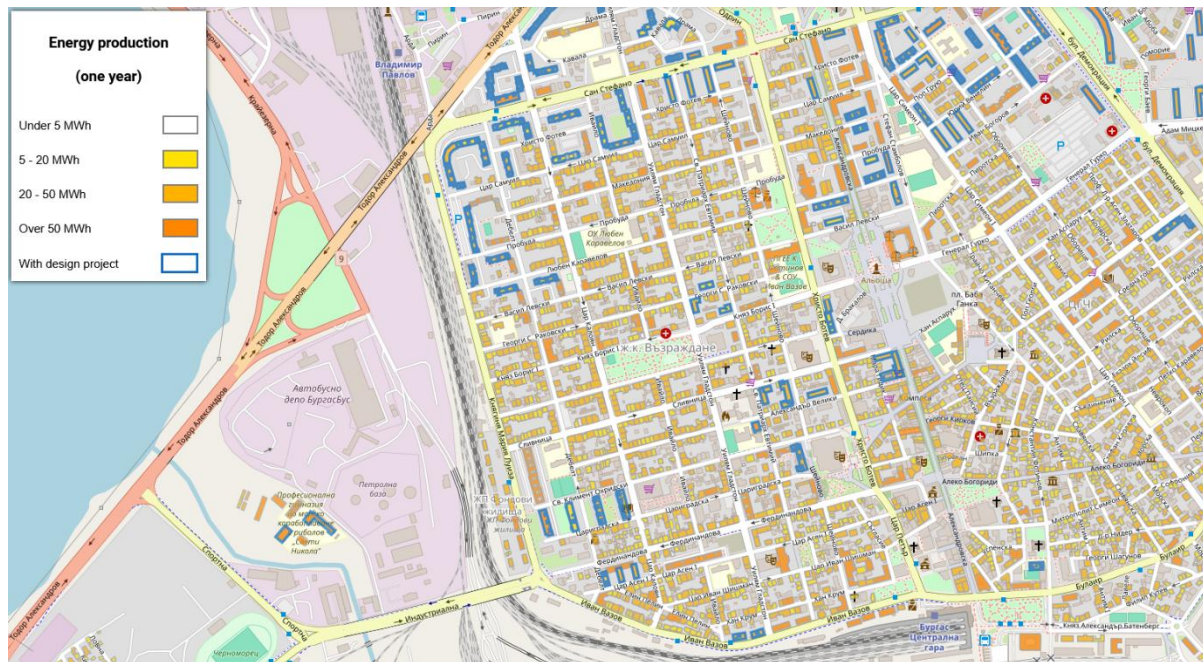


Figure 7: Overview of target neighbourhood at burgas.solarcities.bg



Figure 8: Example of detailed data for residential complex Възраждане 2 available at burgas.solarcities.bg

In selected detailed projects, available for certain buildings, the positioning of PV panels on the roof is specified (Figure 9), along with the connection diagram and equipment specifications (Figure 10). These projects also provide information on installed capacity (in kWp), energy production (in kWh/kWp and kWh/year), the number of panels and inverters, panel surface area (in m²), CO₂ emission reduction (in kg/year), total investment, internal rate of return (IRR, in %), simple payback period, and electricity production costs. Additional details include panel orientation (tilt and azimuth angles), estimated efficiency, and connection schemes with existing electrical grid.

Since these 25 projects contain all the necessary details for an accurate estimation of energy production and investment, average values were calculated based on them and then extrapolated to the remaining buildings in the neighbourhood. This approach is justified, as nearly all buildings share similar orientations - either roughly east-west or north-south.



Figure 9: Example of detailed PV panel positioning data in the project

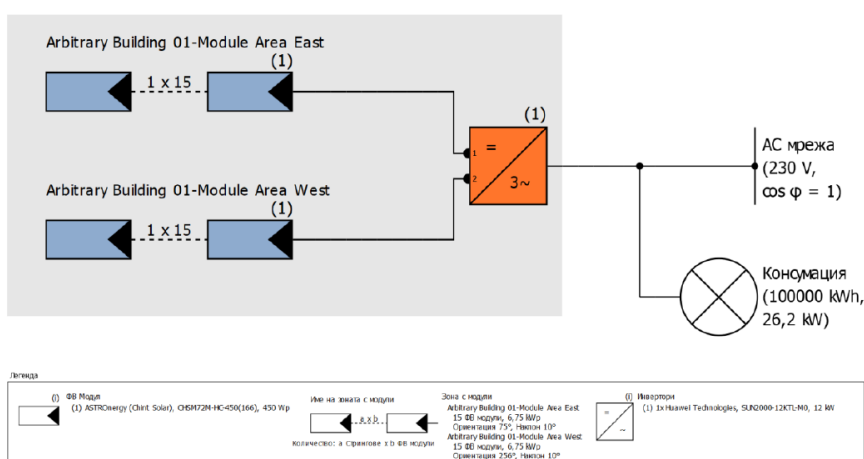


Figure 10: Scheme of PV panel connection with electrical grid in the project

Average values are calculated by dividing sum of specific value (e.g. yearly electricity production for 25 buildings) with 25 buildings' roof area, and they are provided in Table 3.

Table 3: Specific values of key parameters yielded from 25 buildings having detailed projects

Installed power per m ² of roof area	kWp	0.04
Electricity production per m ² of roof area	kWh/year	45.38
PV modules surface per m ² of roof area	m ²	0.17
Investment per m ² of roof area	EUR	28.49

Numbers from Table 3 are then used to calculate values at the level of the entire neighbourhood by multiplying them with roof area of all buildings in the neighbourhood, i.e. 152,126 m² (information available in buildingstock). These values are given in Table 4.

Table 4: Key values at the level of the entire neighbourhood

Installed power	kWp	5,446.93
Electricity production	kWh/year	6,903,775
PV modules surface	m ²	26,310.09
Investment	EUR	4,333,986.79

Compared to the previously calculated annual heating energy demand for the entire neighbourhood (7,102 MWh/year), it is evident that there will be a small energy shortfall. However, it is important to note that in the detailed project plans, only 17% of the available roof area on buildings is utilized for solar panel installation. A significant portion of roof space remains unused. If the average utilization of roof area were increased to 25% - a relatively modest increase - the adjusted numbers would be as shown in Table 5.

Table 5: Adjusted key values at the level of the entire neighbourhood

Installed power	kWp	8,010.19
Electricity production	kWh/year	10,152,611
PV modules surface	m ²	38,691.31
Investment	EUR	6,373,509.99

The adjusted values indicate that not only can the heating energy demands be met, but there will also be a surplus of electricity available for lighting both apartments and common building areas. It should be acknowledged, however, that the calculations presented are based on average values and extrapolated data, each step involving its own assumptions and uncertainties.

Nevertheless, the analysis demonstrates that achieving energy sustainability for the entire target neighborhood is feasible through the installation of photovoltaic (PV) panels on rooftops and inverters within the buildings.

Given the variability of solar energy due to weather conditions, it is unrealistic to expect that all energy needs will be met by renewable sources at every moment. On cloudy or rainy days, electricity will need to be drawn from the grid, but this can be offset by feeding surplus electricity back into the grid during favorable conditions. This dynamic has been anticipated, analysed, and incorporated into all detailed project plans, including calculations of electricity production, grid input, and withdrawal. An illustrative example is shown in Figure 11.

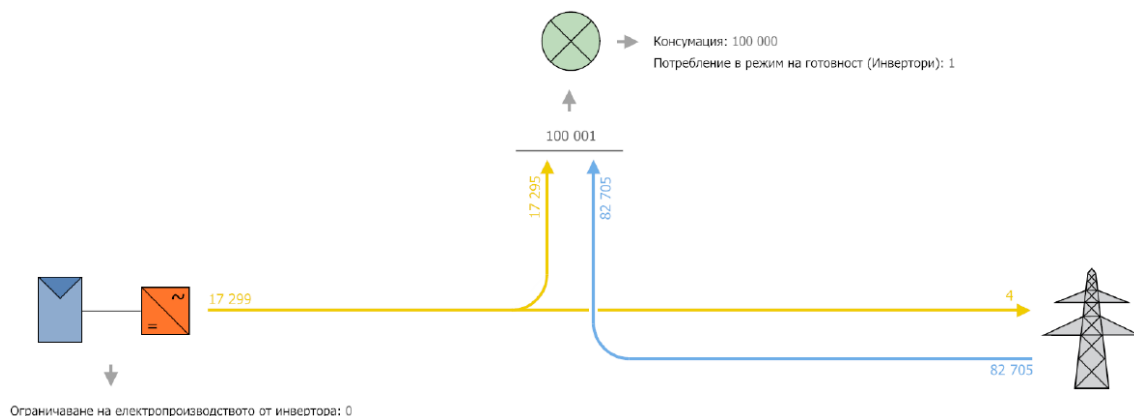


Figure 11: The example of electricity balance for residential complex Възраждане 2

In conclusion, it is possible to say that all heat energy needed to maintain the thermal comfort in fully insulated residential buildings in target neighbourhood in Burgas could be produced from renewable energy sources, namely PV panels. That could be done by producing electrical energy which would be later used by air conditioners. There is possibility to have even surplus, which can be used for lighting. The target neighbourhood could be independent, relying fully on renewables.

It is important to mention that aside of investment shown in Table 5, it would be necessary to provide additional money to buy and install air conditioners in the rest of apartments that are not currently using them. It is hard to estimate this value, as it depends on many factors not observed within boundaries of this project.

Hungary, Budapest

General information

Target neighbourhood in Budapest, part of Józsefváros district, is part of Budapest, measuring approximately 1.20 by 1.00 km and covering area of approximately 0.95 km². It includes 295 residential buildings, many of which are smaller old multi-family apartment buildings (MFAB), closely packed side-by-side and sharing outer walls, with small inner yards or gardens and narrow streets between them. Beside such buildings, there are several large residential buildings or high-rises with several entrances each, separated from other buildings by parks and parking spaces. The following figures show two mentioned types of buildings. There are brand new buildings built between old buildings, often sharing outer walls.



Figure 12: Part of target neighbourhood with close-packed smaller MFABs with inner yards



Figure 13: Part of target neighbourhood with large residential buildings and high-rises

Budapest experiences a transitional climate, lying between a humid temperate and a humid continental climate. Summers are generally warm to hot, while winters are cold and often overcast. From November to early March, temperatures can drop significantly, with nighttime lows of -10°C not uncommon between mid-December and mid-February. Snowfall occurs regularly during this period. Spring (March and April) brings rapidly rising temperatures and unpredictable weather. The long summer season, lasting from May to mid-September, is typically warm or very warm, though sudden heavy showers are common, especially in May and June. Autumn, from mid-September to late October, features mild temperatures, limited rainfall, and plenty of sunshine. However, temperatures can drop sharply in late October or early November. Table 6 below shows average precipitation days and sunshine hours for Budapest for period from 1961 to 1990. As possible to see, Budapest has low number of rainy days (lower than Burgas), and plenty of sunshine (slightly less than Burgas).

Table 6: Average precipitation days and mean monthly sunshine hours for Budapest

	Average precipitation days	Mean monthly sunshine hours
January	6.0	53.8
February	6.0	83.4
March	5.7	133.4
April	5.7	179.5
May	8.0	233.8
June	6.6	250.6
July	6.4	279.4
August	5.6	253.8
September	5.6	195.7
October	6.7	150.7
November	7.1	65.1
December	6.8	49.2
Sum	76.2	1,928.4

Nearly all apartments use natural gas for heating – either through individual furnaces with façade-mounted coaxial chimneys in older buildings, or via district heating systems in newer constructions such as residential blocks and high-rises. Air conditioners are generally not used as the primary source of heating, except during transitional periods when using natural gas is neither practical nor efficient. Few brand-new buildings are heated/cooled by distributed systems using heat pumps, with electricity being the energy source.

Electricity is used for lighting of residential and common spaces in buildings, as well as for preparation of domestic hot water and all appliances.

Choice of renewable energy sources

Given Budapest's climate – particularly the high average monthly sunshine hours – photovoltaic (PV) panels are among the most promising energy solutions. They enable on-site electricity generation, which can be used for heating, cooling, lighting, and powering household appliances. Any surplus electricity could be fed into the grid and sold. One major advantage is that PV panel installation does not require additional land, avoiding disruption to parking areas, parks, or playgrounds. Building orientation is also favourable, as many sloped roofs face south, optimizing solar energy capture.

The electricity generated can efficiently power air-source heat pumps or inverter-type air conditioners, which are particularly suitable for individual room control. These systems are easy to install, relatively inexpensive – even at the high end – and allow for independent temperature regulation across rooms. Importantly, their installation does not significantly alter the building's exterior appearance, as outdoor units can be discreetly placed in inner courtyards.

Maintenance of these systems is straightforward and affordable. With proper care, inverter air conditioners can remain efficient and functional for up to 15 years.

On the other hand, it would be highly beneficial if the existing district heating infrastructure – such as piping and internal building systems – could be reused. Transitioning from natural gas to biomass fuels like woodchips or pellets is a viable alternative, but it presents both technical and logistical challenges, particularly concerning implementation and fuel supply reliability.

One key technical issue is the change in system water temperature. While traditional systems operate at around 90 °C, biomass boilers often supply heat at lower temperatures – around 60 °C. This could necessitate replacing radiators or other heat emitters to accommodate differences in type, size, or shape. Additionally, isolating and converting only certain buildings within a larger district heating network may prove difficult or even unfeasible from a technical and regulatory standpoint. Deciding where to locate a new biomass boiler – whether adjacent to existing infrastructure or in a newly constructed facility – can also be a complex matter. Biomass storage presents another challenge, as a 1 MW boiler may consume up to 3 tonnes of biomass daily, requiring significant storage capacity, which must be located adjacent or in close vicinity to boiler, and logistics planning.

Fuel supply also poses concerns. Sustainable forestry practices in Hungary do support a steady supply of woody biomass – particularly hardwoods such as oak, beech, and acacia. Woodchips are widely available, largely as byproducts of forest thinning, logging residues, and sawmill operations. While Hungary has several wood pellet production facilities, the industry is not yet large-scale. Many producers depend on imported raw materials or export a considerable portion of their output, mainly to countries like Austria, Italy, and Germany. In addition to woody biomass, Hungary generates significant quantities of agricultural residues – such as straw, corn stover, and sunflower husks – that can be used for mixed biomass pellets or direct combustion. However, these residues are more commonly utilized in biogas plants or basic biomass boilers rather than in pelletized form. Although biomass heating is supported by certain government programs, natural gas remains the dominant energy source due to its well-established infrastructure. Furthermore, the price and availability of biomass fluctuate based on seasonal factors, export demand, EU biomass regulations, and local heating market trends.

Implementation of other renewable energy sources in the neighbourhood would have similar pros and cons as in Burgas.

Solar collectors for heating domestic hot water are one of the possibilities, but their retrofit installation requires significant and expensive changes in existing water distribution systems. They would have limited usability during winter, even vacuum ones. They also have relatively complex maintenance as they are sensitive to dust and dirt.

Installing wind turbines directly on buildings would be impractical, technically complex, and ultimately costly. The added mass and vibrations could compromise the structural integrity of the buildings, particularly the old ones. Furthermore, such installations would significantly impact the architectural appearance, what is of great importance for old buildings within this neighbourhood. It would be sensible to install them on top of the large buildings with flat roofs and high-rises. As stated before, any meaningful economic analysis would require detailed data on potential electricity generation, which in turn depends on accurate information about wind patterns and intensity.

Another option is to purchase (or possibly lease) a suitable area in a strategic location, construct a wind farm, and use the generated electricity to supply renewable energy to the target neighbourhood. There are numerous wind farms west of Budapest. However, this would require consideration of legal factors at both local and state levels, complex and substantial funding requirements, and the technical challenges of building the wind farm and transmission infrastructure.

Water-source and ground-source heat pumps present complex systems, require greater maintenance, and come with higher installation costs. Moreover, limited space between buildings poses an additional constraint. Installing any type of heat pump system would necessitate extensive work both inside and outside the buildings, including the installation of appropriate heating elements such as fan coil units or underfloor heating systems.

Based on what has been discussed, seen and noted during site visits, available data from literature and databases, and considering additional consultations with municipality representatives, the renewable energy source of choice for target neighbourhood in Budapest are PV panels.

PV panels

The starting point for assessment of PV panels installation are energy needs for entire neighbourhood after all proposed measures are implemented. This means that energy needs, compared with current, would be considerably lower due to heat insulation of walls, roofs and windows replacement, with numbers available from database of neighbourhood's buildingstock. As stated in introduction, it is possible to expect additional energy consumption reduction of about 3% due to behaviour change of residents. Data about energy consumption is given in Table 7.

Table 7: Overview of energy needs and savings for Burgas' neighbourhood

Buildings	-	295
Heated area	m ²	590,924
Heat required in current state of building	MWh/year	53,757
Heat required after all architectural measures	MWh/year	24,488
3% reduction due to behavioural change	MWh/year	735
Heat required after all measures	MWh/year	23,753

As possible to see, entire neighbourhood would require 23,753 MWh/year of heating energy to satisfy all heating needs (cooling is not considered). To simplify further calculations, it will be assumed that Seasonal Coefficient of Performance (SCOP) is 3.5, what means that for every 1 kW of electricity consumed, the unit can produce 3.5 kW of heating energy. This value is justified for efficient inverter-type air conditioners in Budapest climate. This further means that:

$$\text{electricity required} = \frac{\text{heat required}}{\text{SCOP}} = \frac{23,753}{3.5} = 6,787 \text{ MWh/year}$$

As stated before, there are several ways to determine possible energy production from PV panels, and the one used in this report is simplified. There is data available from web pages, e.g. budapest.hu/zold-budapest/klima-es-kornyezetvedelem/nappal-hajtva/szolar-terkep, where all basic information are given (e.g. estimated total capacity of solar panels that can be installed in kW, estimated annual amount of electricity that can be produced with solar panels and tilt angles), as shown in Figure 14.



Figure 14: Example of information provided for Budapest

The level of available detail is somewhat lower than that for Burgas, but still sufficient to ensure reasonably accurate calculations for the scope of this report. In addition, as shown in Figure 14, variations exist across different sections of buildings' roofs due to differing slopes and angles, what is beneficial both for an overview and detailed calculations.

To evaluate the potential for self-sufficiency through the use of PV panels, average values were derived from a sample of 30 buildings – representing approximately 10% of the total in the target neighbourhood – randomly selected from the database. These averages were calculated by dividing the sum of specific indicators (e.g. annual electricity production for the 30 buildings) by the total roof area of those buildings. The resulting values are presented in Table 8.

Given that the exact investment cost can vary depending on factors such as documentation requirements, PV panel and inverter brands, labour costs, and installation specifics, an average cost of €2,250.00 per kWp has been used in the calculations. This estimate encompasses all necessary stages, including documentation, system design, equipment (PV panels and inverters), wiring, installation, and commissioning. The price was established based on technical and market data available online for Hungary and, when available, Budapest.

Table 8: Specific values of key parameters yielded from 30 buildings

Installed power per m ² of roof area	kWp	0.08
Electricity production per m ² of roof area	kWh/year	80.05
PV modules surface per m ² of roof area	m ²	0.38
Investment per m ² of roof area	EUR	186.13

Numbers from Table 8 are then used to calculate values at the level of the entire neighbourhood by multiplying them with roof area of all buildings in the neighbourhood, i.e. 142,338 m² (information available in buildingstock). These values are given in Table 9.

Table 9: Key values at the level of the entire neighbourhood

Installed power	kWp	11,775
Electricity production	kWh/year	11,393,581
PV modules surface	m ²	54,387
Investment	EUR	26,493,808.59

It is evident that possible electricity production is almost double compared to the previously calculated annual heating energy demand for the entire neighbourhood (6,787 MWh/year). Hence, not only can the heating energy demands be met, but there will also be a significant surplus of electricity available for lighting both apartments and common building areas. It should be acknowledged, however, that the calculations presented are based on average values and extrapolated data, each step involving its own assumptions and uncertainties.

Nevertheless, the analysis demonstrates that achieving energy sustainability for the entire target neighborhood is feasible through the installation of photovoltaic (PV) panels on rooftops and inverters within the buildings.

Given the variability of solar energy due to weather conditions, it is unrealistic to expect that all energy needs will be met by renewable sources at every moment. On cloudy or rainy days, electricity will need to be drawn from the grid, but this can be offset by feeding surplus electricity back into the grid during favorable conditions.

In conclusion, it is possible to say that all heat energy needed to maintain the thermal comfort in fully insulated residential buildings in target neighbourhood in Budapest could be produced from renewable energy sources, namely PV panels. That could be done by producing electrical energy which would be

later used by air conditioners. There is possibility to have even surplus, which can be used for lighting. The target neighbourhood could be independent, relying fully on renewables.

It is important to mention that aside of investment shown in Table 9, it would be necessary to provide additional money to buy and install air conditioners in the rest of apartments that are not currently having them. This investment depends on many factors not observed within boundaries of this project.

Lithuania, Elektrėnai and Kaišiadorys

General information

The two target neighbourhoods in Lithuania, located in the municipalities of Elektrėnai and Kaišiadorys, are situated 16 kilometres apart and share many characteristics relevant to this report. As such, they will be discussed together in a single chapter. Elektrėnai has 143 buildings, while Kaišiadorys has 72. Almost all buildings in both cities are of the same type, typically under eight storeys and featuring separate entrances. Elektrėnai also includes three high-rise buildings.



Figure 15: Part of target neighbourhood in Elektrėnai

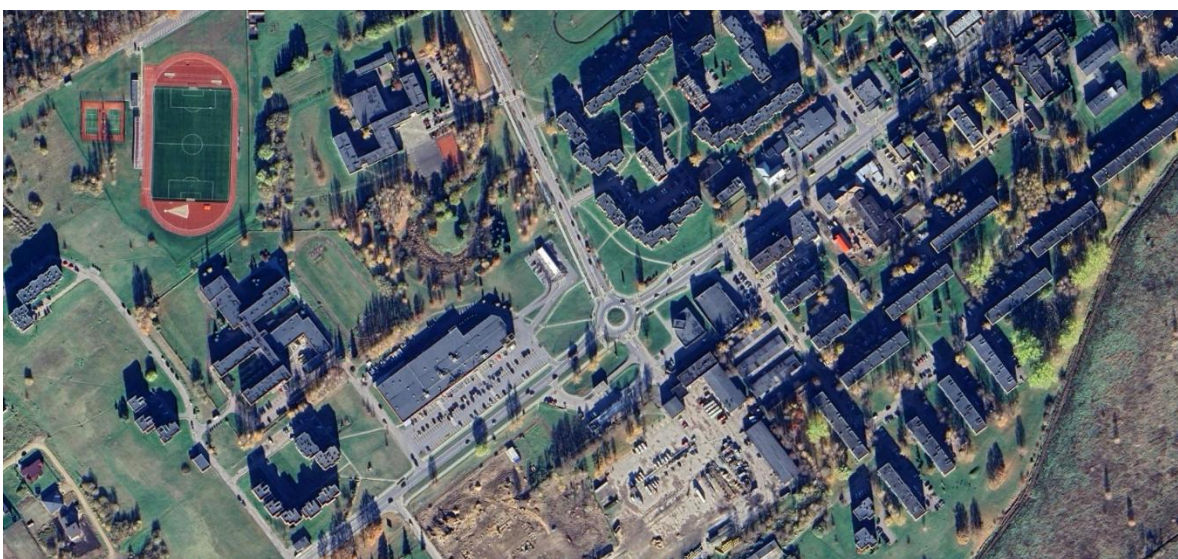


Figure 16: Part of target neighbourhood in Kaišiadorys

While some buildings are arranged in residential blocks, they do not share exterior walls, particularly in Elektrėnai. These buildings or blocks are positioned with sufficient spacing between them, often separated by parks, playgrounds, or green spaces.

Elektrėnai and Kaišiadorys have a humid continental, no dry season, warm summer climate, with summer temperatures going up to 30 °C, while winter temperatures can be as low as -25 °C, with prolonged periods with temperatures -15 °C or lower.

Table 10 below show average precipitation days and sunshine hours for Elektrėnai and Kaišiadorys. As possible to see, both cities have significant number of precipitation days, and lower number of sunshine hours compared with Burgas (2,412) or Budapest (1,928).

Table 10: Average precipitation days and mean monthly sunshine hours for Elektrėnai and Kaišiadorys

	Average precipitation days	Mean monthly sunshine hours
January	14.9	55.7
February	13.2	50.9
March	12.9	103.5
April	12.5	145.1
May	14.9	172.5
June	14.4	167.8
July	15.8	158.3
August	13.0	195.2
September	9.5	160.6
October	11.5	118.9
November	14.9	83.1
December	13.0	48.3
Sum	160.5	1,459.9

All apartments in the multi-family buildings included in this project, in both cities, are connected to their respective district heating systems. In Elektrėnai, the district heating system is supplied by a nearby gas-fired power plant, while in Kaišiadorys it relies on biomass-based boilers, primarily using wood chips. Each district heating system is a fully developed network that includes a heat source (boilers / heat exchangers), a main heat pipeline, substations, additional exchangers, pumps, automation systems, internal building piping, and heating units (most often radiators). As most of buildings are constructed during approximately the same period, they share similar architectural features and heating system designs.

Air conditioners are not used as the primary source of heating, and small number of outdoor units is visible on the buildings. They can be used during transitional periods when district heating system is not in use.

Electricity is used for lighting of residential and common spaces in buildings, as well as for preparation of domestic hot water and all appliances.

Choice of renewable energy sources

Consideration of renewable energy sources in Elektrėnai and Kaišiadorys is rather complex and less straightforward compared with Burgas and Budapest, as climate and weather conditions are quite different.

Kaišiadorys already has a fully operational district heating system that uses woodchips as a renewable energy source. However, photovoltaic (PV) panels remain one of the most promising complementary

solutions and are encouraged during building renovations. PV systems allow for on-site electricity generation, which can be used for cooling, lighting, and powering household appliances, and in some cases, even for heating. Any excess electricity can be fed into the grid and sold. A key advantage of PV panel installation is that it requires no additional land, thereby avoiding any impact on parking areas, parks, or playgrounds. The buildings are spaced sufficiently apart, eliminating concerns about shading or interference from neighbouring structures. Additionally, the prevalence of flat roofs makes many of these buildings well-suited for PV installation.

On the other hand, reusing the existing district heating infrastructure in Elektrėnai, such as piping and in-building systems, would offer significant advantages. Transitioning from natural gas to biomass fuels like woodchips or pellets is a feasible alternative, though it does involve some technical challenges. Traditional systems typically operate at temperatures around 90 °C, whereas biomass boilers often deliver heat at lower temperatures, approximately 60 °C. This difference may require replacing radiators or other heat emitters to match the new system's specifications in terms of type, size, or design. Finding suitable locations for new biomass boilers and fuel storage should not pose a problem, given the plenty of space between buildings and other structures. Moreover, if this transition has been successfully implemented in Kaišiadorys, there is good reason to believe it can also be achieved in Elektrėnai.

Harsh winter conditions with strong winds and low temperatures would make use of air-source heat pumps or inverter-type air conditioners impractical, but not impossible. At that low temperatures they cannot work as efficient, thereby making them consume a lot of energy, while requiring significant increase of maintenance works. Other types of heat pumps (ground- and water-source) could be used, but they require significant investment and, possibly, change of heating bodies or other parts of heating system, as such systems are usually low-temperature.

Installing wind turbines directly on buildings would be impractical due to technical complexity and high costs. The added weight and vibrations could compromise the structural integrity of buildings and would also significantly alter their architectural appearance.

There is also an option to construct a wind farm at suitable location outside of target neighbourhoods and supply them with generated renewable electricity. However, wind energy potential for large-scale wind farms in Lithuania is limited by less favourable wind conditions, particularly inland. As a result, wind energy development is concentrated in coastal region. In east, wind farm expansion is further constrained by national defence regulations, protected areas, landscape preservation, and other territorial restrictions. Nevertheless, there are ongoing plans for large-scale wind energy projects, with a projected capacity of approximately 680 MW. Energy harvested at this wind farm would be used to support energy independence of entire municipalities or cities.

Based on what has been discussed, seen and noted during site visits, and considering additional information provided by municipality representatives, the renewable energy sources of choice are biomass for district heating system in Elektrėnai and PV panels in both Elektrėnai and Kaišiadorys.

Biomass in Elektrėnai

The objective of this measure is to replace the existing heat source—currently a gas-fired power plant—with biomass-fired boilers using pellets or woodchips. The remainder of the heating system, including piping, radiators, valves, and other components, would remain unchanged. However, implementing this measure solely for apartment buildings is challenging, as the district heating network also supplies heat to various other consumers, such as public buildings, commercial facilities, and individual houses. Nonetheless, the purpose of this project and report is to assess the feasibility of achieving energy self-sufficiency through the exclusive use of renewable energy sources. Therefore, the calculations will focus only on the buildings located within the target neighbourhood.

Power required to maintain inner temperature inside of the buildings can be calculated as follows:

$$Q_{total} = \sum (U_i \times A_i \times \Delta T)$$

Here, U_i are U coefficients for walls, roofs, windows and floors, A_i are areas of walls, windows, floors, and roofs, and ΔT is difference between outer (-22 °C) and inner (20 °C) design temperatures. Areas and U -values of walls, windows, floors, and roofs can be taken from buildingstock (values for the case when entire building is insulated), while temperature difference is 42 °C. Now it can be calculated:

$$Q_{total} = 209,758 \times 0.23 \times 42 + 41,629 \times 1.10 \times 42 + 59,910 \times 0.42 \times 42 + 60,424 \times 0.17 \times 42 = 5,438,599 \text{ W}$$

This value should be increased for the efficiency, which is usually 85%, but varies depending on fuel moisture content, boiler modulation, ash handling and heat losses. In addition, good practice is to have certain reserve, usually about 15%. Therefore, the boiler power should have 7.4 MW of thermal power.

Determining the optimal location for a new biomass boiler, whether next to existing infrastructure or within newly constructed facilities, is a complex task that extends beyond the scope of this report. Such a decision involves numerous technical and legal considerations. Additionally, biomass transportation and storage must be carefully planned, as a 1 MW boiler can consume up to 3 tonnes of biomass per day, requiring storage to be situated adjacent to or very near the boiler. If technically feasible, the existing heat source could remain on standby and be used in emergencies or as backup.

It is difficult to provide a precise estimate of the investment required to replace the existing heat source with a biomass boiler. The cost largely depends on technical specifics that fall outside the scope of this report – for example, whether one or multiple boilers will be installed, which buildings will be connected to the system, and the level of automation and control systems to be implemented. Additionally, the cost of land for constructing the boiler house(s) is another significant variable. Based on available studies, the total investment could range between €3.5 million and €5.3 million.

PV panels in Elektrėnai and Kaišiadorys

As energy needed for heating and maintaining thermal comfort inside of the buildings in both target municipalities will be provided by using biomass boilers, electricity produced by PV panels could be used for lighting, home appliances, air-conditioning during transitional periods or summer. The calculation of possible energy production used in this report is simplified, as detailed approach would require more details. As there are no other sources of input information, web page globalsolaratlas.info is used, with all required information, such as specific photovoltaic power output in kWh/kWp or direct normal and global horizontal irradiation in kWh/m². This is shown in the following figures.

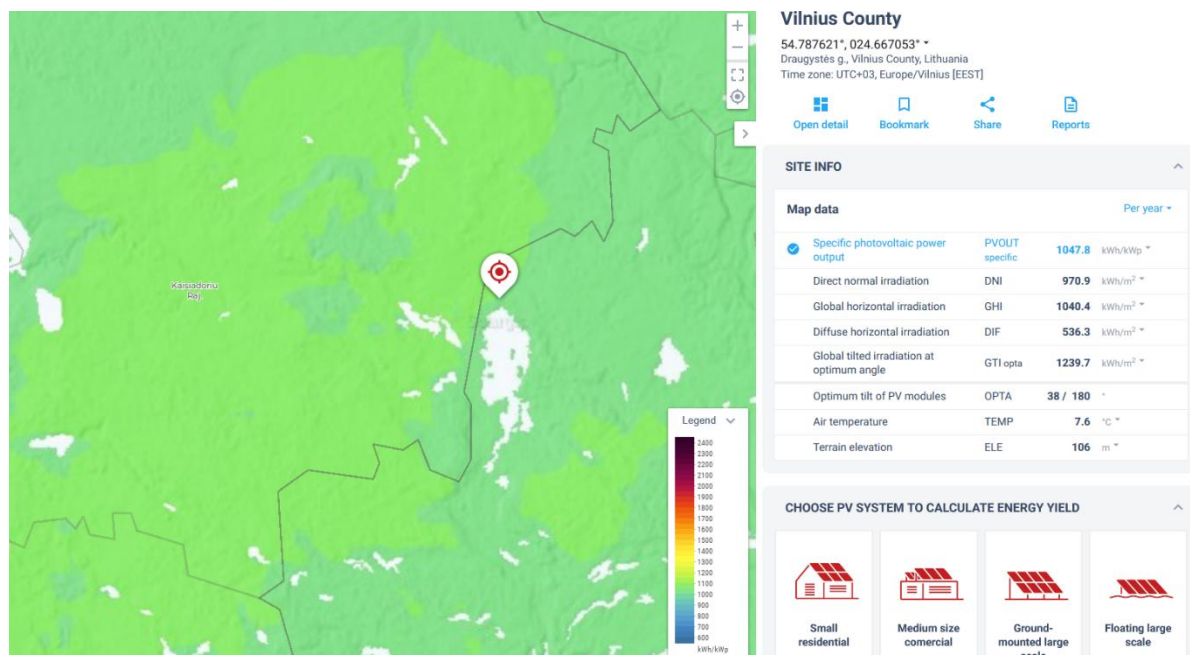


Figure 17: Example of information provided by globalsolaratlas.info for Elektrėnai

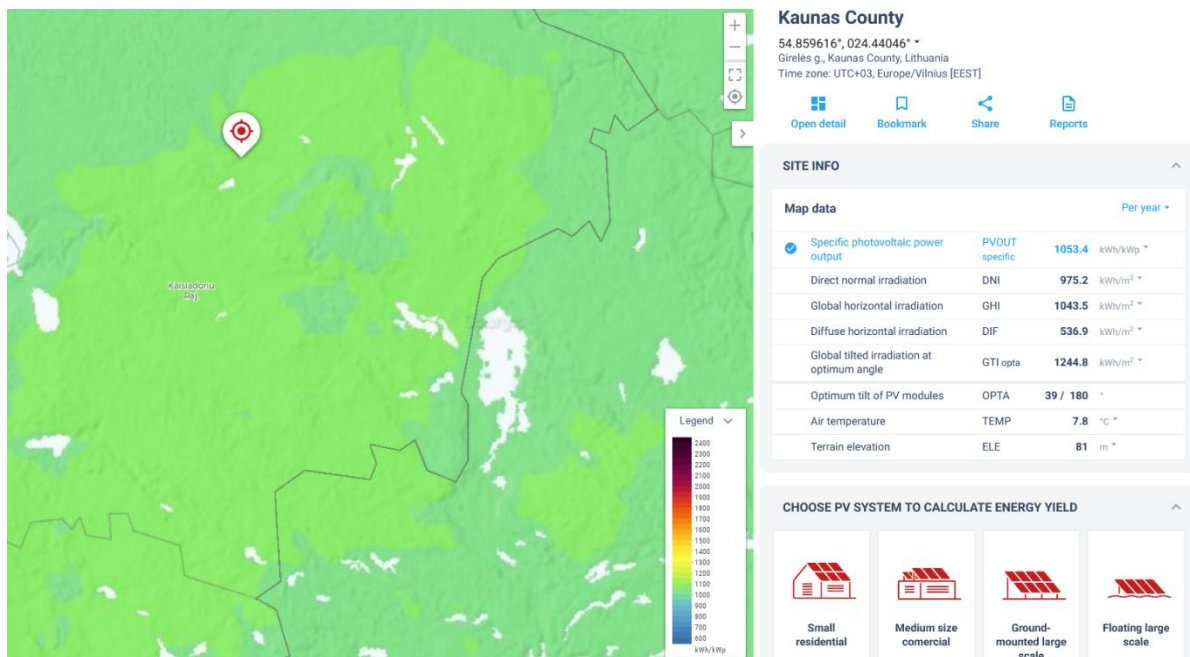


Figure 18: Example of information provided by globalsolaratlas.info for Kaišiadorys

Additional information on panel tilt angles, monthly average power output, and average hourly generation profiles can be obtained for each building, as illustrated in the following figures. By default, the data is presented for 1 kWp of installed solar capacity, though this value can be modified as needed. This data, along with other relevant inputs, is used for detailed calculations that must be performed individually for each building and then aggregated at the neighbourhood level. However, applying this approach across the number of buildings considered in this report is time-consuming, and hence simplified one is used, which is based on data available from buildingstock (e.g. roof area) and average values of irradiation.

Monthly averages

Total photovoltaic power output

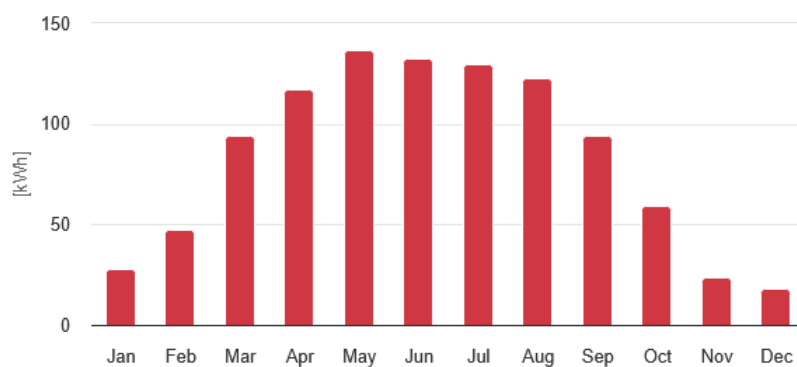


Figure 19: Monthly average output for installed capacity of 1 kWp for Elektrėnai

Monthly averages

Total photovoltaic power output

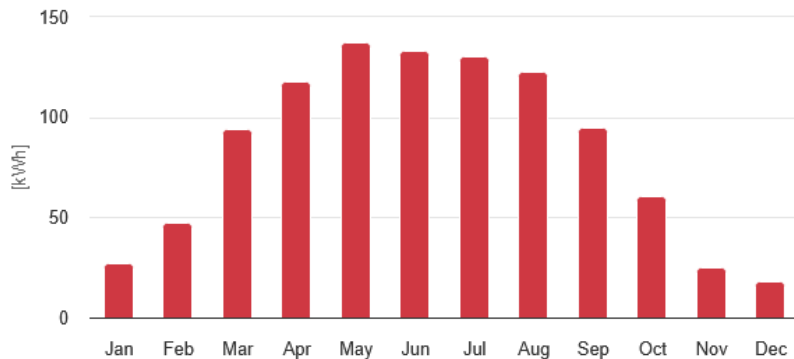


Figure 20: Monthly average output for installed capacity of 1 kWp for Kaišiadorys

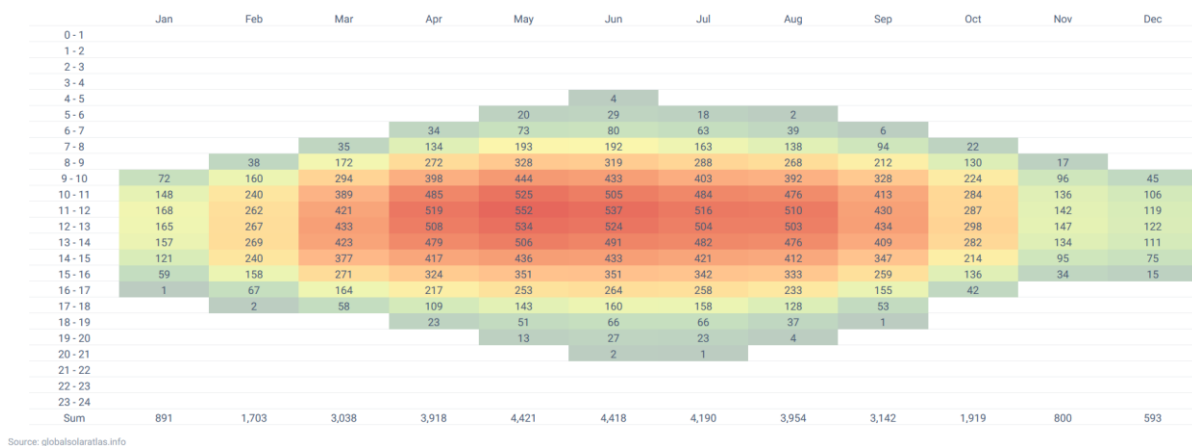


Figure 21: Average hourly profiles for installed capacity of 1 kWp for Elektrėnai

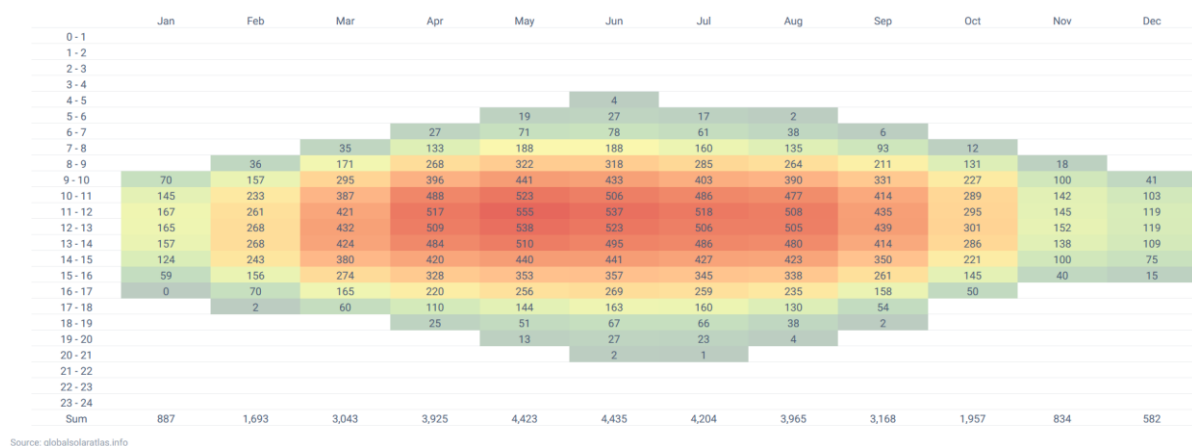


Figure 22: Average hourly profiles for installed capacity of 1 kWp for Kaišiadorys

To evaluate the potential of using PV panels, it is assumed that 20% of roof's area can be used for PV panels. This value is rather conservative, as it can be higher, but it is considered that roofs are used for other purposes as well. At globalsolaratlas.info it is possible to find the value of global tilted irradiation at optimum angle in kWh/m². These values are valid if panels are tilted at optimum angle. Due to various limitations and constraints on the roofs (e.g. chimneys, ventilation shafts, elevator houses, atriums), PV panels will not always have the optimum angle. Hence, it is justified to estimate that yearly production

will be 70% of that with optimum angles. Based on yearly electricity production, it is possible to calculate the power of PV panels, as specific photovoltaic power output is available.

Given that the exact investment cost can vary depending on factors such as documentation requirements, PV panel and inverter brands, labour costs, and installation specifics, an average cost of €1,150.00 per kWp has been used in the calculations. This estimate encompasses all necessary stages, including documentation, system design, equipment (PV panels and inverters), wiring, installation, and commissioning. The price was established based on technical and market data available online for Lithuania.

The resulting values are presented in Table 11 for Elektrėnai and Table 12 for Kaišiadorys.

Table 11: Key parameters for PV panels in Elektrėnai

Total roof area	m ²	60,424
PV modules surface	m ²	12,085
Global tilted irradiation at optimum angle	kWh/m ² year	1,239.10
Actual global tilted irradiation	kWh/m ² year	867.37
Total actual global tilted irradiation	kWh/year	10,482,058
Specific photovoltaic power output	kWh/kWp	1,047.80
Installed photovoltaic power	kWp	10,003.87
Investment	EUR	11,504,453.65

Table 12: Key parameters for PV panels in Kaišiadorys

Total roof area	m ²	45,261
PV modules surface	m ²	9,052
Global tilted irradiation at optimum angle	kWh/m ² year	1,244.80
Actual global tilted irradiation	kWh/m ² year	871.36
Total actual global tilted irradiation	kWh/year	7,887,767
Specific photovoltaic power output	kWh/kWp	1,053.40
Installed photovoltaic power	kWp	7,487.91
Investment	EUR	8,611,098.96

Comparing numbers from tables above with those in buildingstock, it is evident that possible electricity production from PV panels would be more than sufficient for heating all the buildings in both target neighbourhoods. However, as heating would be provided by biomass boilers, this electricity is available for lighting both apartments and common building areas, usage for home appliances, outdoor lighting, or even charging electric vehicles. It should be acknowledged, however, that the calculations presented here are based on above-mentioned average values, assumptions and approximations. It is important to mention that one of the key assumptions is that all buildings are fully insulated.

The analysis demonstrates that using PV panels in conjunction with biomass boilers would lead to secure self-sufficient supply of heat and electric energy in both target municipalities. Nevertheless, given the variability of solar energy due to weather conditions, electricity will need to be drawn from the grid on rainy or cloudy days, but this can be offset by feeding surplus electricity back into the grid during favourable conditions. The target neighbourhoods could be independent, relying fully on renewables.

Conclusion

This report explores the potential of utilizing locally available renewable energy sources to achieve energy self-sufficiency in four target neighbourhoods: one located in the Vazrazhdane district of Burgas (Bulgaria), another in the Józsefváros district of Budapest (Hungary), and two in Elektrėnai and Kaišiadorys (Lithuania).

One of the main challenges lies in the significant differences between these neighbourhoods. For example, the neighbourhoods in Burgas and Budapest consist mainly of closely packed small multi-family apartment buildings and larger residential blocks, whereas in Lithuania, buildings are more spaced out, with numerous parks and green areas in between.

Climate variation is another important factor. While Elektrėnai and Kaišiadorys share a similar climate, it is substantially different from that of Burgas and Budapest, not just in terms of temperature but also sunshine hours, wind patterns, and precipitation. These differences influence the choice of renewable energy technologies, particularly when considering design temperatures and heating needs.

From a technical standpoint, solutions vary widely. For instance, in Elektrėnai, it is relatively simple and cost-effective to replace the existing natural gas-based district heating system with a biomass boiler, while maintaining the rest of the system. In contrast, similar interventions in Burgas and Budapest would pose significant engineering challenges, as only part of the buildings is connected to district heating system, while the rest relies on individual gas-powered façade furnaces.

As such, all renewable energy options have been assessed individually for each neighbourhood, taking into account relevant technical, climatic, legal, and urban planning factors. Input from municipal representatives has been crucial in guiding the selection of appropriate technologies.

For certain renewable solutions – such as solar thermal collectors for domestic hot water, wind turbines, wind farms, and water-source or ground-source heat pumps – have been concluded that they will not be analysed in detail due to technical complexity and legal uncertainties, which is beyond the scope of this report.

The only neighbourhood where a biomass boiler is proposed as a primary intervention is Elektrėnai, where it would replace the current natural gas-based heat source within the district heating system.

However, one common measure that can be recommended across all four neighbourhoods is the installation of photovoltaic (PV) panels for electricity generation.

- In Burgas, a significant number of apartments already rely on air conditioners or air-source heat pumps for heating and cooling. When combined with PV panels, this presents a viable path toward energy self-sufficiency, thanks to the mild climate.
- In Budapest, a similar approach is feasible, although fewer apartments currently use such electric heating and cooling systems.
- In Lithuania, despite a colder climate and fewer sunny days, PV panels still offer benefits. While biomass boilers remain the main strategy for heating, PV panels can still provide a meaningful contribution to electricity production which can be used for lighting, appliances and electric vehicles.

In summary, the analysis – though based on simplified approach as well as some assumptions and approximations – indicates that:

- In Burgas and Budapest, PV panels alone could meet heating energy demands when combined with electric heating systems.
- In Elektrėnai and Kaišiadorys, a mix of biomass heating and PV electricity generation could secure both thermal and electrical self-sufficiency.

At the conclusion of the analysis for each target neighbourhood, an investment estimate is provided, covering all material and labour costs required for proper implementation of the proposed measures. These estimates are based on available data and should be treated as indicative figures only. A more accurate assessment should be conducted following the development of detailed technical and project documentation.

While intermittency of solar energy remains a factor – requiring grid electricity during cloudy or rainy periods – this can be mitigated by exporting surplus energy during periods of high generation. Overall, the target neighbourhoods have the potential to become self-sufficient by relying solely on renewable energy sources.





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