Stockholm Environment Institute

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Disclaimer

Due to data confidentiality requirements and the sensitive context in Ukraine, specific the name and the location of the studied object, numerical values, and input datasets have been intentionally removed or represented by the symbol "X". All analytical results, findings, and conclusions presented in this report remain valid and are based on verified data.

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Cover photo: Canola field in Ukraine by Myroslava Bondar/Pexels

Abbreviations

AAHP - Air-to-Air Heat Pump

AWHP - Air-to-Water Heat Pump

BESS – Battery energy storage system

CAPEX – capital expenditure

EBRD – European Bank for Reconstruction and Development

EFC – Equivalent full cycles

EIB – European Investment Bank

EPTATF – Eastern Partnership Technical Assistance Trust Fund

ESSF – Energy Security Support Facility

FL – Framework Loan

Gcal – Gigacalorie

GWh – gigawatt-hour

HOMER Pro – Hybrid Optimisation of Multiple Energy Resources

IBRD – International Bank for Reconstruction and Development

IDA – International Development Association

IDP – internally displaced person

IFI – international financial institution

JASPERS – Joint Assistance to Support Projects in European Regions

kW – kilowatts

kWh – kilowatt-hour

LCOE – Levelised Cost of Electricity

Li-ion – Lithium-ion

MIGA – Multilateral Investment Guarantee Agency

NEFCO – Nordic Environment Finance Corporation

NIP – Neighborhood Investment Platform

NPC – Net Present Cost

OPEX – Operational expenditure

PV – photovoltaic

RDNA – Rapid Damage Needs Assessment

SME – small and medium-sized enterprises

TA – Technical Assistance

UIF – Ukraine Investment Framework

UIF MIIR – Municipal, Infrastructure & Industrial Resilience

UMIP – Ukraine Municipal Infrastructure Programme

URP – Ukraine Recovery Programme

URTF – Ukraine Relief, Recovery, Reconstruction and Reform Trust Fund

V – Volts

WB – World Bank

WP – Work package

WWHP – Water-to-Water Heat Pump

Introduction

Ukraine's green transition is not solely an environmental imperative, but a strategic necessity for national resilience, economic competitiveness and a just society.[1] As Russia targets Ukraine's energy infrastructure, decentralised energy solutions contribute to both community resilience and environmental sustainability. As Ukraine boosts its efforts to transition to green energy to improve its energy resilience and support the EU accession efforts, municipal governments are increasingly exploring opportunities for renewable energy projects.

The UA-GRIDEX project aims to support the resilience and uninterrupted access to essential municipal services for residents of a major city located in Ukraine [the name of the city removed here and further for security reasons], which hosts a significant number of internally displaced people (IDPs). The project foresees the application of an energy modelling method to evaluate the range of renewable electricity generation options and storage solutions for one of the most significant municipal water supply stations in the city that serves around 400,000 residents of the city and nearby villages. It also presents the macro-level evaluation of the heating infrastructure of the selected water station, aiming to identify which heating technologies would most effectively make the facility resilient to potential energy shortages and reduce its reliance on centralised fossil supplies. Finally, to ensure the viability of the proposed solutions, the project presents a mapping of [primarily international] funding sources that could be used to finance the installation of the most effective renewable energy solution proposed in the modelling work packages.

The findings and recommendations developed under the UA-GRIDEX project are presented in this report. The report includes outcomes of the macro-level assessment of the heating infrastructure opportunities for the selected object and the solution assessment evaluating the efficiency of renewable energy technology that can improve energy resilience of this object and make it more independent from fossil supplies. Moreover, the report encompasses the mapping of funding opportunities for implementation of the most cost-effective renewable energy solutions for heating and electricity supply.

Objectives of work packages

The UA-GRIDEX project's methodology was designed to support the development of decentralised renewable energy solutions for a critical municipal infrastructure in

[1] https://green-agenda.org/storage/public/JiZC2a7L1Q04d71C9XbSzzuEsBymgA-metaVWtyYWluZU5hdGlvbmFsQXNzZXNzbWVudCAoMSkucGRm-.pdf

Ukraine. The project is structured across six interlinked work packages that guide the entire process from site selection to dissemination of results. The approach combines technical modelling and financial planning to ensure feasibility.

The project started with the identification and selection of a suitable prototype site under **Work Package 1 (WP1)**. In close consultation with the beneficiary municipality, we identified a vital public utility in need of renewable energy solutions for enhancing resilience of the supply of critical resources for the citizens and advancing community resilience. The selected water station ensures the quality of the water supply for 400,000 residents, as well as the operation of the sewage system across the city and its surrounding suburbs. Understanding the facility's importance, the study has chosen it as a vulnerable hot spot for the analysis. Due to the ongoing military conflict in Ukraine, the energy supply to the station might be highly vulnerable. Integrating renewable energy technology as the facility's primary source will guarantee its energy resilience and independence.

After the facility was selected, **Work Package 2 (WP2)** focused on preparing an overarching methodological framework and developing a data collection method. In collaboration with the municipality and technical personnel at the facility, the project team gathered comprehensive technical and operational data. The data collected under WP2 laid the foundation for the project's modelling and analysis phases.

Work Package 3 (WP3) applied an energy modelling method to evaluate a range of renewable electricity generation options and storage solutions for the facility. The modelling was carried out using HOMER Pro (Hybrid Optimisations of Multiple Energy Resources), a widely used tool for the simulation and optimisation of hybrid and decentralised energy systems. The modelling study assessed the performance of different renewable and battery storage technology combinations, such as solar photovoltaic systems, wind turbines, battery storage, and backup generation. The suitable technology combinations were evaluated based on key criteria such as technical reliability, energy sufficiency, economic viability, and renewable energy penetration.

In **Work Package 4 (WP4)**, the research examined the macro-level evaluation of the heating infrastructure of the selected plant. During this modelling, the research explored opportunities for modernisation and decentralisation of the heat supply with the integration of more efficient and more sustainable technologies. Based on the interest of the stakeholders, the research considered various heating alternatives and compared them based on energy efficiency, sustainability of the environment, and operational cost-effectiveness. The aim was to identify which heating technologies would be the most effective for making the facility robust while reducing the reliance on centralised fossil supplies.

Work Package 5 (WP5) focused on mapping funding opportunities for implementation of the most cost-effective solutions determined in the framework of the modelling work (WP3, WP4). In 2025, multiple international and national financing programs are available. However, each of them comes with unique opportunities and limitations, making it crucial to analyse these programs to determine the most suitable combination of financing sources and actionable next steps towards securing funds for installation of renewable energy technologies at the selected water station.

Finally, the findings of this report will be disseminated in the framework of the **Work Package 6 (WP6)**. The findings, methodologies, and tools developed throughout the project will be shared with key stakeholders in Ukraine, Sweden, and Estonia.

Work Package Methodology and Results

WP1 - Object Selection

During WP1, the study team closely consulted with the water station's administrators and staff to identify vulnerable hotspots in the beneficiary municipality that could serve as a pilot location. After several rounds of meetings and discussions with the administrative and technical experts, a municipal water facility was selected as the primary test site for the modelling exercise. This water facility plays a crucial role in delivering a continuous water supply to 400,000 people. The river closer to the objective is the primary source of water for the water station, and from there, the water has been extracted upstream near the water treatment plant and transported to the main pumping stations in the northern part of the city. The first two water treatment facilities have a capacity of X m3/day, which were commissioned in the 19XXs and 19XXs, and the third plant has been operational since the 19XXs, which has an additional capacity of delivering X m3/day. In total, the facility can provide up to X m3/day and serve at least 400,000 people.

Several interrelated factors were considered during selecting the water facility, such as the fact that it is an essential public infrastructure that is highly energy-intensive, with substantial energy consumption to power the facility's mechanical equipment and heat requirements. This high level of energy demand provides a significant opportunity to explore the potential deployment of renewable energy systems. In addition, the facility's continuous reliance on the grid makes it highly vulnerable during the ongoing military aggression. In case the energy grid supply fails or is compromised due to natural disasters or technical failures, the facility's ability to function is completed, potentially limiting or depriving 400,00 citizens of access to water.

Exploring the potential of deploying renewable energy technologies to the facility will decrease its high reliance on the central grid and vulnerability. Also, integrating renewables will not only increase resilience but also directly align with the city's long-term objectives of decreasing carbon emissions and improving energy independence. The study at the facility generally represents a strategically valuable and technically viable site for showcasing the value of resilient energy planning. Possibly, this study can be replicated within other comparable critical infrastructure objects in the future.

WP2 - Development of the Survey and Data Collection

Once the water supply station was identified as the pilot location of the study, the study team developed two comprehensive surveys to perform modelling under WP3 and WP4. These surveys aimed to understand the current electrical and thermal energy infrastructure and its demand to evaluate its potential for integrating a renewable energy system. The survey results provide information on modelling the renewable energy systems based on the experts' perspective on technical needs, stakeholders' interests, and feasibility, supporting investment planning and enabling evidence-based decision-making for sustainable infrastructure development.

The WP3 survey thoroughly assessed the water supply station for the feasibility and efficiency of renewable energy technologies that can be utilised as inputs in the modelling stage. Through the survey results, the study has identified that the facility operates continuously (24/7) with consistently high and stable electricity consumption. The average daily electricity consumption is around X kWh, leading to an annual consumption of around X million kWh. The peak energy demand of the facility reaches around X kW, and there are no reported seasonal or operational spikes. The national power grid serves as the primary energy source, and the facility uses the diesel generator as a backup source with a rated capacity of X kW, though this system is rarely used. The electricity supply maintains voltage levels at X kV and a frequency of X Hz.

The WP4 survey identified existing heating infrastructure and options for decentralised, low-carbon heating technologies, such as suitable heat pumps and their required solar thermal systems. Based on the survey results, currently, the facility uses a mixed heating system; part of the premises is connected to the municipal district heating network (fueled by natural gas). At the same time, an electric boiler serves the remainder. The peak daily heating demand is approximately X kilowatt-hour (kWh) (X Gigacalorie (Gcal)), with an annual demand of X kWh (X Gcal). There is no significant seasonal fluctuation in thermal demand. Operating costs for the heating system exceed X million UAH annually.

Despite the high cost and fossil fuel dependency, as of now, no renewable systems have been installed within the facility, nor have any options been previously considered. There is space on the territory of the facility for renewable installations, including heat pumps and/or solar panels. To implement these renewable technologies, the survey results show several significant hurdles, including regulatory, technical, and financial challenges. Additionally, there's no dedicated budget allocated for modernisation, and the facility lacks the in-house expertise needed to operate or maintain renewable energy systems. Overall, saving energy resources, pursuing long-term sustainability, and reducing costs are currently key priorities for the water supply station. In summary, the survey results highlight both the need and potential for renewable heating system integration. While funding and technical readiness remain major constraints, the availability of space and institutional interest in energy efficiency create a strong foundation for future feasibility assessments and investment in low-carbon heating solutions.

The main interest of the beneficiary municipality is to explore the opportunities of installing solar PV, wind and battery technologies within the available facilities. The survey identified a significant opportunity for installing renewable technologies within the facility area, approximately 8,712 m², including the on-land and rooftop space, available to use for installation of renewable technologies. Currently, the site is looking to install solar PV as its potential option due to its feasibility. Also, the preliminary data indicate the average wind speed at the facility is approximately 4 m/s, which might be insufficient for large-scale wind power. Currently, the facility does not have any renewable energy systems or energy storage technologies installed, but the experts and management of the facility express interest in relevant opportunities.

The minimum energy of X kW annually mandates the reserve of X kW to ensure the uninterrupted continuity of vital water treatment functions. A seamless power supply is paramount for daily operation and is the top priority when designing any future energy upgrade of the system. Despite these obstacles, the representatives of the municipality and the water supply station have clearly expressed a priority for solar technologies and a strong interest in achieving long-term costs and energy stability. From an environmental and regulatory perspective, the facility is subject to special permitting and zoning requirements for renewable energy installations. Nonetheless, there are no known environmental hazards, such as flooding or extreme weather, that would impede implementation. There are no plans for facility expansion, thus no anticipated increase in energy demand. Overall, the surveys' outcomes highlight the selected water supply station as a technically suitable candidate for renewable energy integration. While financial and institutional barriers persist, the site's inherent operational stability, available space, and energy-intensive profile collectively designate it as an ideal pilot location for renewable energy deployment and modelling.

WP3 & WP4 - Modelling for Sustainable Electricity and Heating Supply

The water supply station in focus has a significant infrastructure facility designed for a year-round operation. The station has large-capacity centrifugal pumps, pressure regulation systems, electrical switches, and automated control systems that allow water distribution under different demands and pressure conditions. The water station's mechanical systems are energy-intensive, which is reflected in constant high monthly power consumption, usually between X and X million kWh per year.[2]

In addition to its core pumping functions, the facility requires thermal energy for heating purposes, especially during the colder months between October and March. The reported heat demand in Table 1 refers to the thermal energy purchased from the District Heating Network provided by a local heating company. This purchased heat is mainly used to maintain space heating, safe internal temperature and prevent cold in mechanical systems and pipelines.

However, it is important to note that the facility also uses electric heat pumps as part of its internal heating system. These heat pumps supply part of the total heating demand and are powered by electricity. This means that the district heating network only covers a portion of the total heating needs, while the rest is met through electricity consumption. As a result, the recorded "heat demand" in Table 1 only reflects the externally purchased heat from the district heating network. However, the facility's actual total thermal energy use is higher, with part of it embedded in the facility's overall electricity consumption.

Table 1: Electricity and heat purchase data of the facility (ibid.)

Water pumping station, 2024	Electricity consumption, kWh	Heat demand, Gcal
January	X	X
February	X	X
March	X	X
April	X	X
May	X	X
June	X	X
July	X	X
August	X	X
September	X	X
October	X	X
November	X	X
December	X	X

In the modelling process, we have detected the development of a hybrid renewable energy system designed to change the dependence of facilities purchased with locally

[2] Source from water facility – collected in WP2 survey

produced renewable energy. This system meets the station's power and thermal demands through durable, self-borne sources, increasing energy freedom, reducing operating costs, and reducing environmental impact.

1. Modelling for Decentralised Electricity System

The primary objective of this study is to model and design decentralised energy systems for the selected water supply station, focusing on identifying the most cost-effective mix of renewable energy sources. The study utilises HOMER Pro, a globally recognised software platform for optimizing microgrid and hybrid energy system designs to support this objective. HOMER Pro enables comprehensive simulation of both decentralised and grid-connected systems, evaluating hundreds of possible configurations over an annual period. It assesses multiple energy resources such as solar, wind, batteries, and generators to identify the least-cost and most efficient system combinations.[3]

In analysing potential energy solutions for the water supply station, the study will focus on four key metric categories within HOMER Pro:

1. Economic Metrics – These include Net Present Cost (NPC) and Levelised Cost of Electricity (LCOE), which provide critical insights into each system configuration's financial feasibility, total investment, and long-term cost-effectiveness.
2. Energy Metrics – These assess overall energy production and consumption patterns, identifying potential energy surpluses or deficits throughout the year.
3. System Performance Metrics – These evaluate the decentralised system's efficiency, reliability, and operational resilience under various load and weather conditions.
4. Component–specific metrics offer a detailed analysis of the performance and efficiency of individual renewable energy components, helping refine the system design to better suit the needs of the water treatment plant.

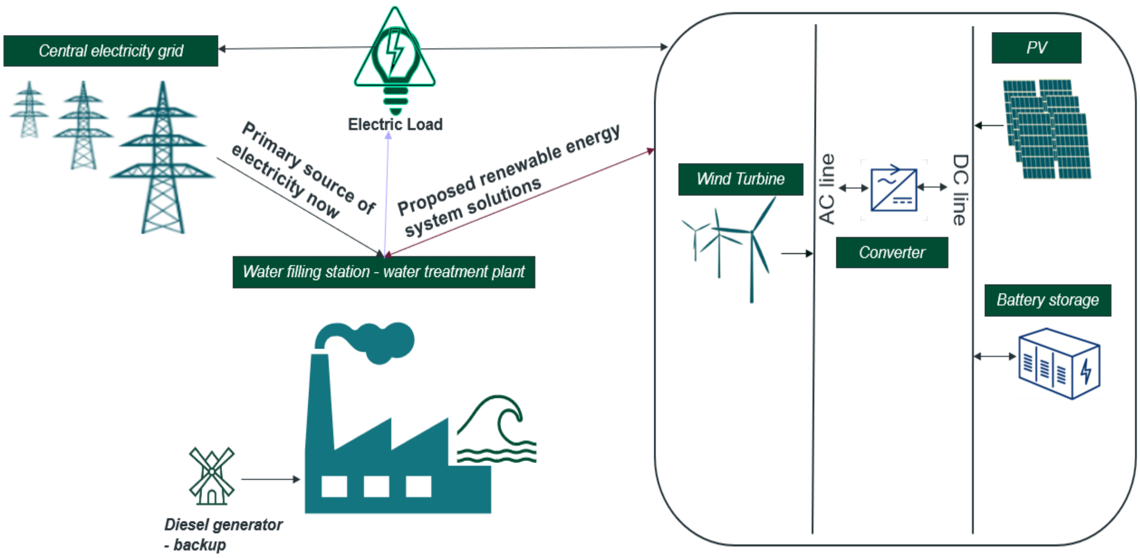
By incorporating solar PV, wind turbine systems, and battery storage to increase energy flexibility, stability, and economic performance, the study aims to provide a strong, economically viable, and environmentally permanent decentralised energy solution to suit the operating demands of the water supply station.

Figure 1 shows the system configuration of the facility's electricity system design, mainly consisting of PV, wind turbine, battery storage, and converter components. Currently, the primary source of electricity is purchased from the central grid. In this study, we will

[3] https://www.homerenergy.com/products/pro/index.html

analyse the possibility of integrating a hybrid energy system and optimizing the effective energy solutions for the facility.

Figure 1: Proposed system configuration for optimisation[4]



The technology specifications we have used in the model are a 2 MW wind turbine, a generic flat plate PV, and a 4Hr 1MWLi battery for storage, where the software optimises the capacity required to fulfil the demand requirements.

PV technology is a rapidly advancing form of renewable energy that converts sunlight directly into electricity using semiconducting materials. Flat plate solar photovoltaic systems are the most widely deployed in various PV system types due to their simplicity, reliability and cost-effectiveness. Flat plate PV modules are usually made of several solar cells that are typically included in the weather-resistant protective layer, usually glass and polymer. These modules are mounted on fixed or adjustable structures and oriented to maximise solar energy capture. The most common material in these modules is crystalline silicon, although thin-film technologies are also used in specific applications.[5]

In fixed systems, panels are installed at a predetermined tilt and Azimuth angle, with a 49.23° tilt and an Azimuth slightly oriented from the south to the west. These angles are optimised based on geographical location to increase the annual solar production. The tracking system, such as a monthly adjustable horizontal-axis tracker, is set, which can

[4] Developed by Author

[5] https://www.eia.gov/energyexplained/solar/photovoltaics-and-electricity.php

increase energy production by allowing panels to adhere to the Sun and the Sun's path more closely throughout the year. Flat plate PV systems work under standard testing conditions (STCs), considering a cell temperature of 25° C and solar radiation of 1000 W/m. However, in real-world scenarios, temperature effects greatly affect PV performance. For example, with a normal temperature coefficient around -0.5%/° C, power generation is usually reduced as the cell temperature rises. In this case, the nominal operating cell temperature (NOCT) is set to 47° C, and the panel efficiency under STC is 13%. The lifetime of PV is considered 25 years.[6]

Another critical factor in PV system performance is the derating factor, which is responsible for real-world losses such as shading, wiring, dust, and inverter disabilities. The derating factor is 80%, indicating a 20% expected system loss under normal operating conditions. Overall, flat plate PV technology represents a mature and scalable solar power generation solution suitable for a utility-scale water supply facility.

Wind turbines convert the wind's kinetic energy into electrical energy using aerodynamic blades and a generator system.[7] Wind turbines on modern utility-scale are highly engineered systems adapted to specific wind regulations through customised power curves and seating strategies. This project used a custom wind turbine power curve to define the output range from 3 m/s to 25 m/s, with a rated capacity of 2 MW received at 13 m/s. Beyond the speed of this wind, power generation remains flat at 2000 kW, which reflects aerodynamic and generator boundaries contained for commercial turbines. The cut-in wind speed is about 3 meters/second, under which the turbine does not produce electricity, and the peak power is at least 25 meters/second. The turbine’s height is set at 97.5 meters, which aligns with modern turbine designs to exploit the speed of high and more stable air at greater height. Power curve data reflects consistent and realistic progress of energy production, in which efficiency at high air speed results in gains in rated output.

To simulate realistic performance, an overall energy loss of approximately 3.5% was applied. This includes availability losses, turbine performance degradation, environmental effects, electrical losses, wake effects and curtailment. These losses are typical in wind modelling tools, resulting in a more accurate representation of actual operational conditions. A basic maintenance schedule has also been considered to simulate downtime and its effects on reliability. Two general maintenance events were modelled at 2700 and 6300 operational hours, each requiring 12 hours of downtime. Although the cost entries were set to zero for simplicity in this model, the inclusion of downtime ensures a more realistic capacity factor calculation over the turbine’s life cycle. Overall, the wind turbine model captures significant aspects of operating performance, including efficiency plateau, turbine control boundaries, and other losses,

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[6] Configurations set for technologies in Homer Pro

[7] https://www.energy.gov/eere/wind/how-do-wind-turbines-work

making it suitable for integration in hybrid renewable systems or standalone wind power evaluation.[8]

The battery energy storage system (BESS) utilised in this project is a 1 MW / 4 MWh lithium-ion (Li-ion) unit, designed to deliver reliable energy storage and discharge over a 15-year operational life. The system is configured with a 600V DC string voltage and operates at 100% initial state of charge (SoC), with a 0% minimum SoC, maximizing usable energy *(ibid.)*.

The selected technology, Li-ion battery, is known for its high energy density, efficiency, and cycle life, which makes it suitable for grid and off-grid applications. The battery is rated as a throughput of 21,081,851 kWh on its life cycle, indicating strong life cycle capacity and performance under the load. The system configuration allows a full load-hour discharge in the nominal power output, supporting peak shaving, energy arbitrage, load shifting and grid support services. External environmental factors, such as temperature fluctuations, have been accounted for to ensure durability and operational reliability in different circumstances in the design and performance of the system *(ibid.)*.

The converter system is a bidirectional power electronic device that manages energy flow between direct (DC) and alternating (AC) systems. It consists of two primary components: an inverter, which converts DC electricity into AC, enabling the delivery of power to AC loads or the grid and a rectifier, which converts AC electricity into DC, allowing devices or systems that operate on DC to be powered from an AC source.[9] Designed with 95% efficiency and a 15-year service life, the converter ensures high performance and long-term reliability in energy systems. It is essential in maintaining voltage and frequency compatibility, ensuring energy can be safely and effectively transferred between different parts of the electrical infrastructure *(ibid.)*.

While the converter operates independently, it is a critical interface component for many energy systems. It supports PV systems by converting DC power generated into grid-compatible AC and battery energy storage systems by managing charging (AC to DC) and discharging (DC to AC) processes. Its versatile functionality makes it essential in modern hybrids and renewable energy applications.

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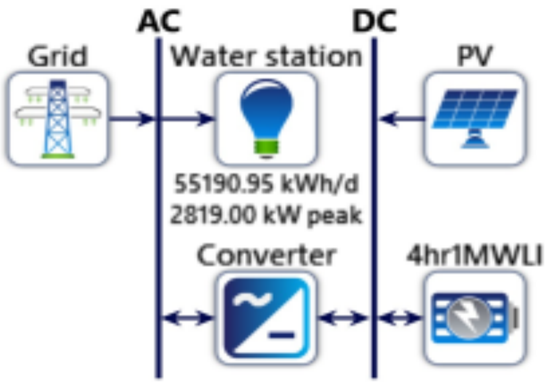
[8] https://www.homerenergy.com/products/pro/index.html

[9] https://www.anker.com/blogs/ac-power/understanding-the-basics-how-a-dc-to-ac-converter-works

1.1. Electricity Modelling Results: 100% Decentralised Renewable Energy Solution

Using HOMER Pro, simulations were conducted based on a system configuration designed in alignment with stakeholder interests. The results focus on two primary technology combinations: Combination 1 – PV + Battery and Combination 2 – Wind + Battery, both modelled without grid support. The microgrid facility has a daily energy demand of 55,164 kWh and a peak load of 2,819 kW. It is important to note that no excess electricity produced by the renewable system is exported to the grid; the facility is only permitted to purchase electricity from the grid during periods of load shortage**.** The following sections present the performance results for each configuration in meeting the facility’s energy requirements.

Figure 2: Design of a 100% renewable hybrid energy system for optimisation



Source: Homer pro

1.1.1. Combination 1 – PV + Battery Results Summary

This section showcases the performance outcomes of the system setup with a decentralised energy solution utilizing PV generation and battery storage. The configuration was selected to assess solar energy viability as a primary power source to meet the daily electricity demand for the facility. Using HOMER Pro, the system was designed to adapt to energy production, storage and remittance, which ensures balance between technical reliability and economic viability. The optimisation results generated multiple viable system configurations with similar technology combinations; however, this particular setup was selected, making it the most cost-effective among the alternatives. The following analysis summarises the system’s generation capacity, storage adequacy, load coverage, excess energy, and overall economic performance.

Table 2: Combination 1 - Required capacity of the Solar battery solution

Component	Name	Size	Unit
PV	Generic flat plate PV	59,282	kW
Storage	Generic 4hr 1MW Li-Ion	72	strings

System converter	System Converter	9,458	kW

The generic flat plate PV system provides an annual power generation of about 62,777,186 kWh, or 62.78 GWH. This figure reflects the total energy production expected under the average solar resource conditions. The installed capacity and performance of the system are characterised by an average output of 7,166 kW and a capacity factor of 12%, which is specific for solar PV systems working in areas with moderate to good solar radiation. The capacity factor is the maximum possible output which is calculated as the ratio of real production in a period if the system operates at full capacity[10] continuously, which underlines the intermittent nature of solar energy. With 4,379 annual operating hours, the PV system does not run throughout the year due to daily and seasonal variations in the availability of sunlight.

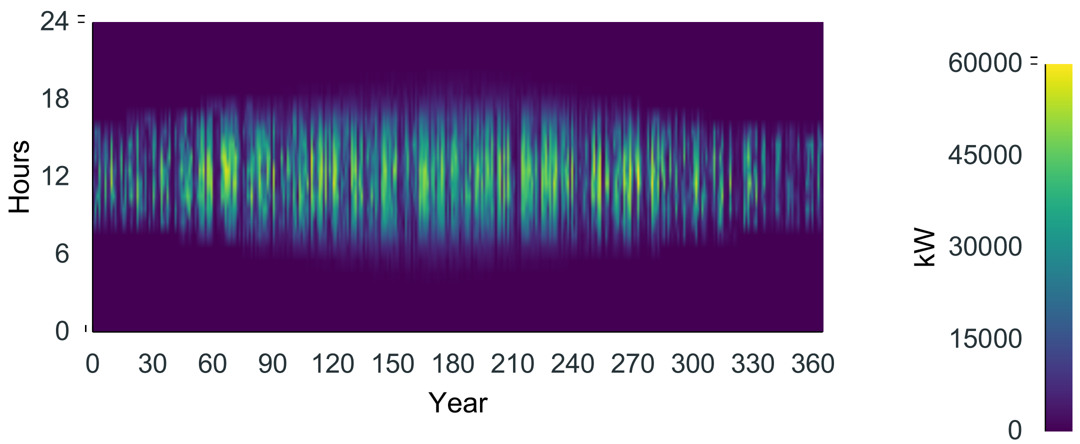
The daily average energy production estimate is approximately 171,992 kWh, which consistently contributes to power grids or load demands based on use patterns and storage capabilities. However, the system generates an important surplus of electricity, in which the annual additional power is estimated at 40,503,999 kWh. This high amount of unused energy is mainly due to a stakeholder-flown barrier that prohibits the export of electricity to the grid, as defined in the system design parameters within HOMER Pro. As a result, any power generated beyond immediate load and storage capacity is refused. Although this result refers to the system working to overcome the current obstacles, it also underlines the importance of large storage capacity or advanced load management strategies to utilise additional generations better and reduce energy waste within the closed system.

Conversely, the system also experiences periods when it cannot meet the demand. Despite its adequate production capacity, it records an unmatched electric load of 13,274 kWh per year, reflecting a small but significant reliability interval. This decrease occurs when the energy demand exceeds the immediate generation and the stored energy available, especially during low solar production or the night period. In addition, the lack of capacity of 17,693 kWh/year indicates moments when the generation of the system and storage peak demand cannot meet the demand, even when grid imports are technically available. This is partly due to the economic remittance strategy of HOMER Pro, which can allow a slight decrease in the capacity rather than more investment, and the modelling perception that the grid only serves as a backup source, not a sink. These values, although small, highlight that when the system meets most of the load in the year, it lacks excess or rapid response ability during the interval, indicating the potential requirement of supporting power sources, increasing battery capacity, or better system design for peak load management.

[10] https://www.sciencedirect.com/topics/engineering/capacity-factor

From an economic point of view, the system level cost of the system (LCOE) is 0.0741 euro per kW-hour (€/KWH). This value represents the average cost of the production of a unit of electricity over the entire life cycle of the system, including factoring in capital expenditure, operation and maintenance costs and energy production of the system[11]. At this rate, the cost is competitive with many traditional energy sources and reflects the economic viability of solar PV technology, especially when storage and demand-party is effectively integrated with management.

Figure 3: Combination 1 - Generic flat plate PV Output



The BESS supporting the photovoltaic installation comprises 72 units of 1 MW, 4-hour Li-ion batteries, arranged in 72 parallel strings. This configuration is designed to meet many important roles, including grid stabilisation, energy time-shifts (supply when supply is exceeded by demand and discharging), and backup power to supplement the variable PV system variable PV system.

The system's total nominal and usable capacity is 303,579 kWh, assuming 100% availability, which means the full capacity is accessible for energy storage and discharge at any time. While working on a bus voltage of 600 volts (V), the battery system can maintain the system autonomy for 132 hours, theoretically supporting the significant load for more than five days without recharging. This level of autonomy refers to a strong backup capacity, which is important to maintain power supply during low solar production or an extended period of grid outage.

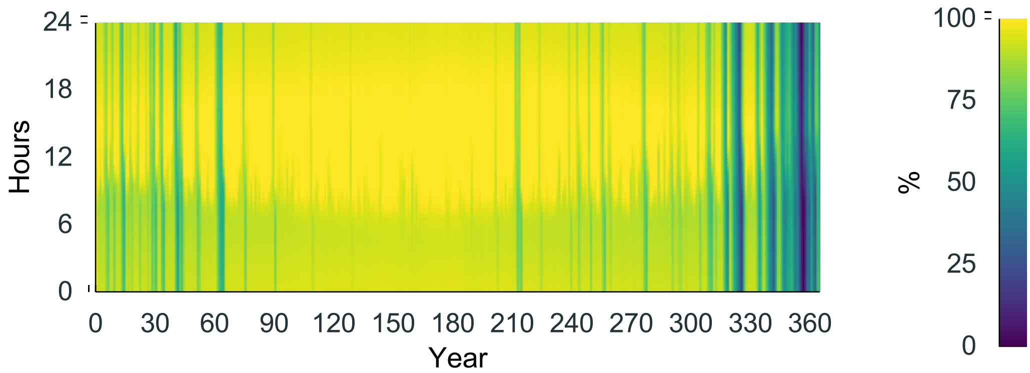
[11] https://www.energy.gov/sites/prod/files/2015/08/f25/LCOE.pdf

Regarding energy flow, the system receives 12,073,604 kWh of energy annually through charging, while distributing 10,991,388 kWh per year through discharging. The discrepancy between the input and the output is attributed to the transformation and energy loss caused by internal system disabilities. It creates a round-trip efficiency of about 91%, which corresponds to high-performance Li-ion technology. Despite high efficiency, the system still increases the annual energy deficit of about 1,214,130 kWh. It is lost due to self-discharge, undercharging, or over-discharging for an additional 131,914 kWh per year. These figures outline the importance of careful battery management to reduce unnecessary losses and maintain optimal performance.

The battery's operating throughput is measured at 11,585,940 kWh per year, representing the total amount of energy cycled through the annual system. The battery passes through 38.2 equivalent full cycles (EFCs) per year, translating to an average of 0.105 cycles per day. This relatively low cycling rate suggests the system is lightly used in daily deepening discharge, contributing positively to battery longevity. Light cycling is ideal for maintaining long-term battery health, as excessive cycling or deep discharge may expedite a decline.

Financially, the battery system increases the storage cost by 0.0250 euros per kW of discharge energy. This metric captures the cost associated with the battery's fall overtime, which helps to estimate long-term operating expenses. Over its life cycle, the system is estimated to give a total throughput of 173,789,099 kWh before reaching the end of its life. It underlines the capacity of the system to provide high cumulative throughput long-term energy storage services, supports the variability of the PV system and power supply, and increases the overall flexibility and reliability of the infrastructure.

Figure 4: Combination 1 of Generic 4hr 1MW Li-Ion State of Charge (%) 100%



The converter system, a central component of hybrid power infrastructure, has been rated at 9,458 kW and plays an important role in managing energy flow between DC sources (such as PV array and battery storage) and AC load or grid. This device has been tasked with converting DC-to-AC and AC-to-DC, depending on whether the energy is drawn from the solar array and battery or transported to the grid and load.

During a year, the converter operates for about 8,753 hours, almost continuously reflecting its importance in the round-the-clock operation of the hybrid system. The average production is 2,298 kW, showing that while the converter has a high rated capacity, its average function is about 24.3% of its maximum capacity. This capacity factor reflects the changing nature of solar energy production and the use of batteries, as these energy sources do not continuously produce or demand peak power, the converter is often operated on a partial load to meet the demand for ups and downs.

From an energy perspective, the converter processes a sufficient annual energy input of 21,190,972 kWh, of which 20,131,423 kWh is transported to AC after conversion. This results in the conversion deficit of 1,059,549 kWh per year, mainly due to the underlying disabilities in power electronics, such as heat production and switching losses. These disadvantages translate into a conversion efficiency of about 95%, which is specific to modern, high-demonstration converters in hybrid systems.

The system's output varies greatly throughout the year, depending on the availability of power from PV or battery, ranging from 0 kW to 2,819 kW of 2,819 kW during the passive period. It highlights its ability to effectively react to the dynamic output range converter's flexibility, high demand, or minimum generation time to load the diversity and energy remittance requirements.

Figure 5: Combination 1 - System Converter Inverter Output (kW)

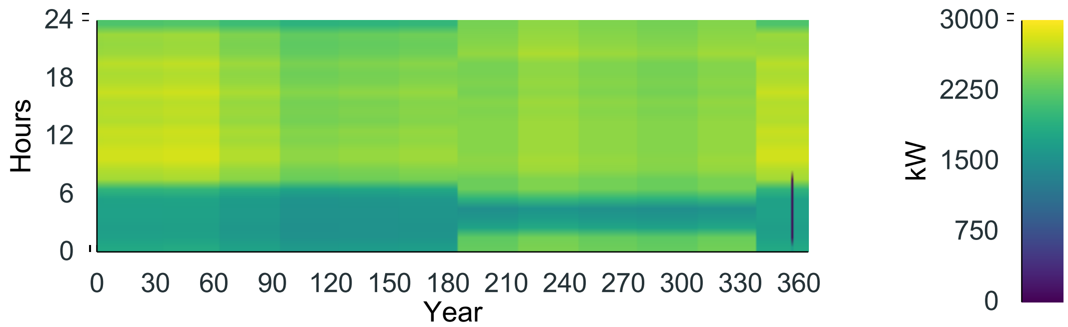
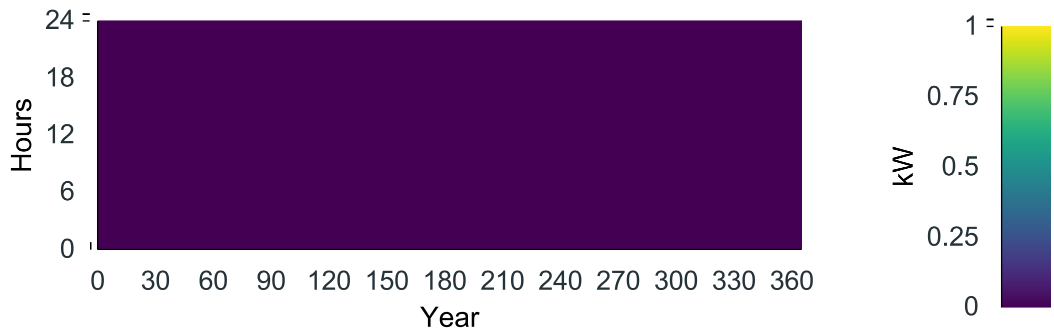


Figure 6: Combination 1 - System Converter Rectifier Output (kW)



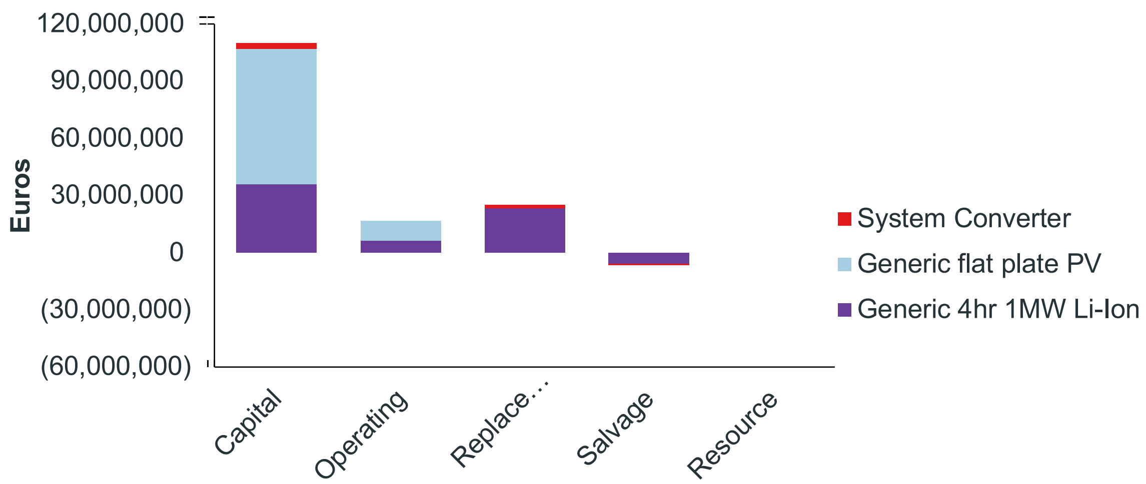
The combination is estimated to have a total life cost of a hybrid energy system of €146 million, including capital investment, operational expenditure, replacement costs and salvage values. The lifetime of the project is considered 25 years. The generic 4-hour 1 MW Li-ion battery system is approximately €59.8 million of the total cost. This includes €36.0 million in capital costs, €6.31 million in operating expenditure and €23.3 million in replacement costs. The negative salvage value of €5.81 million refers to the expected decommissioning or disposal costs at the end of its operational life.

The generic flat plate PV system represents the most significant single investment with a total cost of €81.5 million. This cost is mainly accounted for by the high capital expenditure of €71.1 million in operational costs and €10.4 million in the project's lifetime. In particular, the PV system does not incur any replacement or salvage costs, which is specific to solar installations with long operating lifetime and minimum maintenance requirements.

The system converter contributes a relatively small share of the overall cost, totalling €4.22 million. This includes €2.84 million in capital expenditure and €1.84 million in replacement costs, with a minor negative salvage value of €458,240. No operating costs were reported for the converter.

Overall, the project's capital expenditure is €110 million. An additional €16.7 million is responsible for operating costs and €25.1 million for replacement costs. The total negative salvage value of €6.27 million separates these figures slightly. The investment profile shows that the PV system dominates advance costs, while battery storage contributes significantly to long-term operations and replacement expenses. The relatively inexpensive converter plays an important role in system integration and power flow management.

Figure 7: Cost summary of combination 1



The overall hybrid energy system, including solar PV, lithium-ion battery storage and a power converter, displays an integrated approach to renewable power generation and energy management. The total lifetime costs are a high investment in €146 million and an LCOE of €0.412 per kWh, both in infrastructure and long-term operational efficiency. While LCOE is relatively higher than traditional grid electricity, it includes reliable, transmitted renewable energy, factoring in energy storage, system autonomy, and the cost of giving minimal unmet load. The system receives a balance between stability and flexibility, offering a clean energy solution for applications where energy freedom, grid support, and off-grid capacity are prioritised.

1.1.2. Combination 2 – Wind+Battery Results Summary

This section underlines the performance evaluation of the second system configuration, characterised by integrated wind energy production with battery storage. Unlike a PV-based setup, this configuration takes advantage of the availability of wind resources to provide a renewable and decentralised energy solution again without any grid export. The system was imitated using HOMER Pro to determine its ability to meet the energy needs of the convenience store while maintaining cost-effectiveness and operational reliability. The wind + battery model was evaluated not only on its standalone viability, but also as a potential supplement or alternative to solar-based systems, especially in scenarios with favourable air conditions. The summary below contains details of the system's energy production, storage performance, demand coverage, energy busted and economic indicators.

Table 3: Combination 2 - Required capacity of wind battery

Component	Name	Size	Unit
Wind turbine	Leitwind 90 2000kW	7	ea.
Storage	Generic 4hr 1MW Li-Ion	24	strings
System converter	System converter	2976	kW

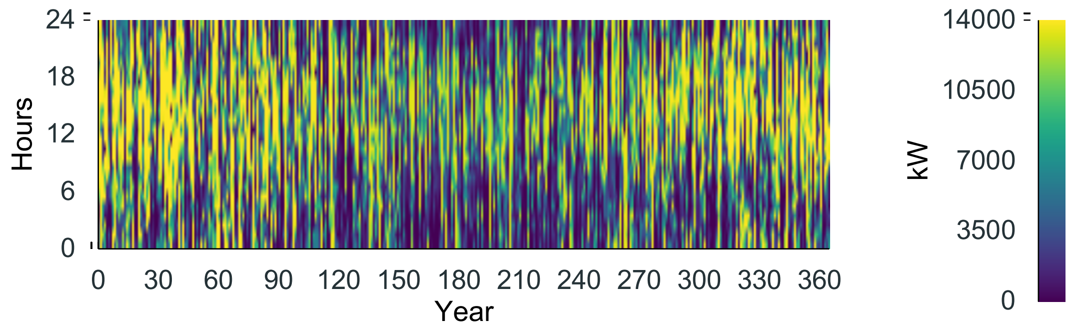
Leitwind 90 2000kw wind turbine generates about 58,500,266 kWh (58.5 GWH) of electricity annually. This figure represents the expected energy production under average wind resource conditions and indicates the performance of continuous wind production in the year. The system has a total rated capacity of 14,000 kW, with an average production of 6,678 kW, resulting in a capacity of 47.7%, a strong indicator of reliable and continuous generation specific to high-performing wind installations in favourable wind areas.

The wind turbine operates for 7,825 hours per year, with high availability and wind resources. However, the minimum output falls to 0 kW, reflecting a period of cool air or system downtime, while the maximum output reaches 14,000 kW, indicating strong peak performance during optimal air conditions. The entry rate of 290% indicates a significant surplus in the relative generation of demand on the site, mainly AC load consumption of 20,128,704 kWh per year.

This overproduction results in an adequate annual additional power of 37,439,326 kWh, emphasizing the generation capabilities of the system beyond local consumption. While this grid indicates the capacity for export or energy storage opportunities, it also shows the need for increased load integration or conservation strategies. Despite high energy production, there are still small reliability gaps, which lack an unmatched electric load of 15,993 kWh/year and a lack of capacity of 19,969 kWh/year, with a brief interval, where the demand is greater than the supply, during low air conditioning or sudden peak loads.

From an economic point of view, the wind turbine system claims the highly competitive LCOE of 0.0244 €/KWH, underlining its cost-effectiveness in renewable energy production on utility-scale. This low LCOE reflects not only the efficient performance of the system, but also its favorable air position, operational longevity and adaptable life cycle costs.

Figure 8: Combination 2 wind turbine output



A generic 4-hour 1 MW Li-ion System consists of 24 battery units configured in 24 parallel strings (a battery per string), working on a 600V voltage. The total nominal and usable capacity are 101,193 kwh, which is capable of supplying power for an extended period during extreme demand or generation shortage.

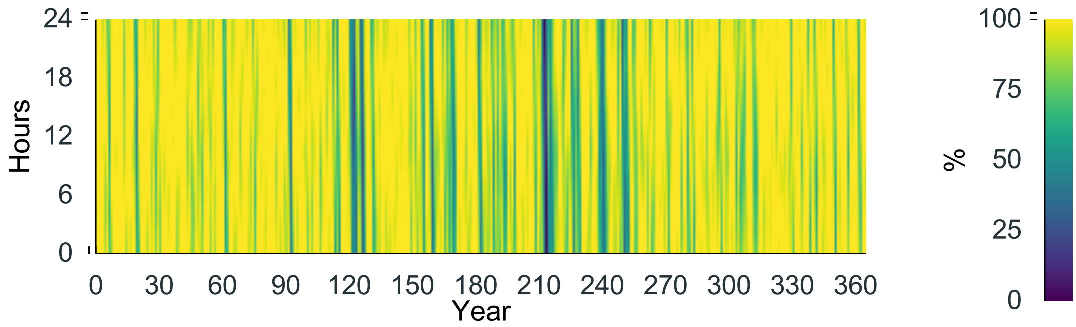
With a 44-hour rated discharge autonomy, the system extends beyond traditional 4-hour BESS applications, providing greater flexibility. This extended autonomy allows it to act as a long-term storage unit, which supports the long-term outage or intermittent renewable downtime.

On an annual cycle, the battery receives 4,740,972 kWh of energy input and distributes 4,271,854 kWh as a useful output, totaling 4,502,930 kWh annual throw. The system increases 474,367 kWh in energy loss and 5,248 kWh in storage deficiency, which is specific to lithium-ion technology and reflects the expected round-trip efficiency behavior. These disadvantages represent a proper efficiency margin for this scale system, about 10% of energy input.

The cycling profile is relatively conservative, with 44.5 EFCs per year or about 0.122 daily cycles. This suggests that the system is used more for strategic backup and peak load support than for daily cycling. This use contributes to patterns' longevity, supporting 15 years of the expected operational life and 67,543,943 kWh's life through energy throughput.

The average energy price is reported as 0 €/kWh in the model, likely due to on-site renewable generation, while storage wear costs are estimated at 0.025 €/kWh, reflecting the system's life cycle reduction. This cost structure enhances the economic appeal of low-wear systems, particularly when wind power is combined with other energy sources.

Figure 9: Combination 2 of battery storage output



The system converter is a significant component designed with a rated power capacity of 2,976 kW and supports an average output of 463 kW. It operates on a wide range of electric levels from 0 kW to peak output, ranging from a minimum to 2,819 kW. A capacity factor of 15.6% reflects the actual use of the converter compared to its maximum theoretical operation, which is specific for converters supporting variables or internal weight and renewable sources. While working for about 2,767 hours per year, the system processes vital energy versions with remarkable efficiency. The converter handles 4,271,854 kWh of energy input on the annual cycle, providing 4,058,261 kWh of usable energy production. This conversion translates to 213,593 kWh, or approximately 5% energy input, which aligns with standard performance expectations for high-quality power electronics under partial-load conditions. Power conversion damages from disabilities, internal resistance heat, and other minor electronic dissipation. The relatively low loss rate increases the converter's value in integrated renewable and storage systems, where efficiency is important for overall system performance and economics.

The performance of the converter indicates strong operations under the ups and downs in the position of the load in the metrics, indicating enough headroom to adjust to the demand peaks. Its flexibility and mid-range capacity factor suggest it is effectively tuned to match internal sources (e.g., solar or wind) or variable battery removal patterns.

Figure 10: Combination 2 of system converter inverter output (kW)

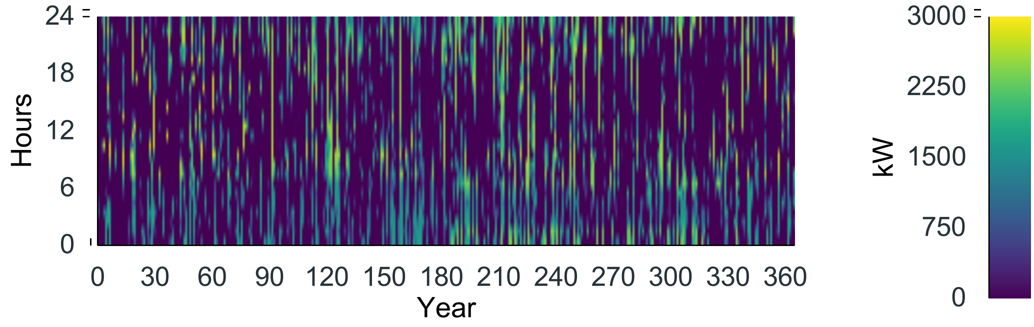
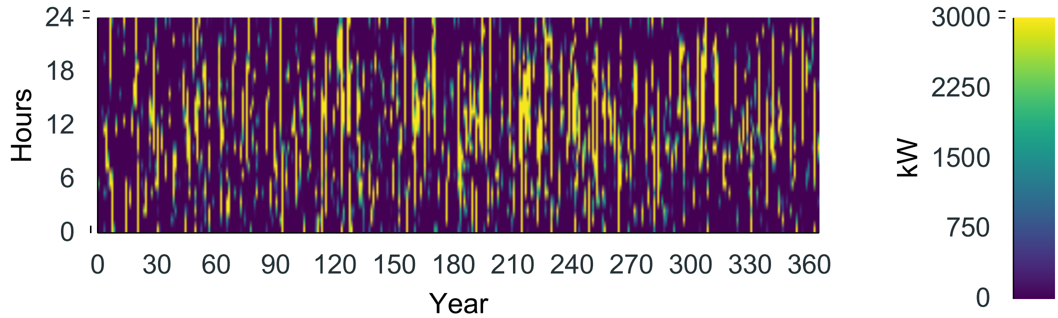


Figure 11: Combination 2 of system converter rectifier output (kW)



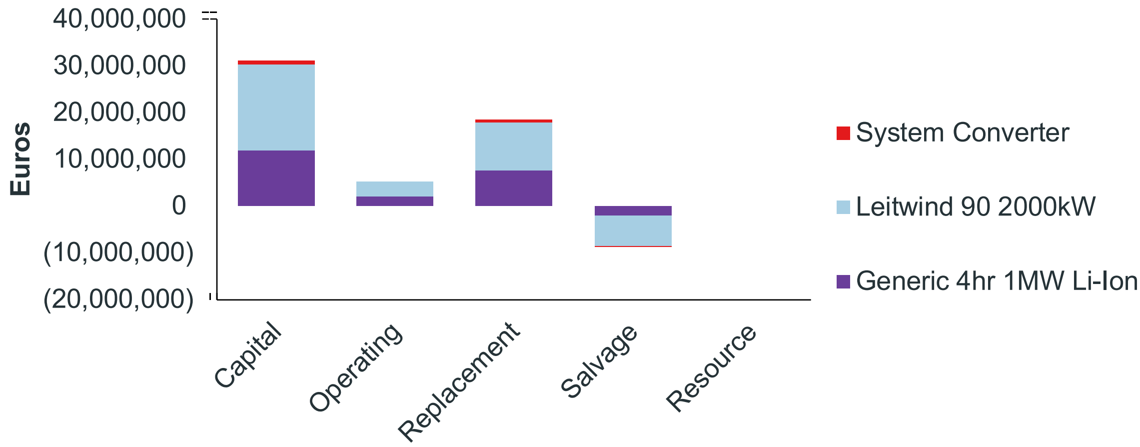
The total lifetime cost of the hybrid energy system is €46.2 million, including all major cost categories: capital investment, operational expenditure, component replacement, and end of life salvage values. A generic 4-hour 1 MW Li-ion battery storage system costs a total of €19.9 million on its operational life. This includes capital investment of €12.0 million, €2.10 million in operating costs and €7.77 million in replacement expenses. A negative disposal value of €1.94 million reflects exceptional decommissioning and disposal costs, which are a specific idea for the lithium-ion system due to handling and recycling requirements.

Leitwind 90 2000KW Wind Turbine System represents the largest cost section, with a total of €25.0 million. This includes €18.2 million in capital costs, €3.19 million in operating expenditure and €10.2 million in replacement. The cost of €6.61 million accounts for the estimated expenses associated with turbine disintegration and site restoration at the end of its life cycle. The wind system typically leads to significant end-of-life costs due to the scale and complexity of decommissioning.

In total, the project cost €31.1 million in capital expenditure, €5.29 million in operating costs, and €18.5 million in replacement spending, partially offset by a negative salvage value of €8.70 million. While the wind component dominates the capital and long-term cost profile, the battery system introduces notable replacement expenses. The converter system is low cost but necessary for reliability and performance. This investment structure highlights the economic balance between high-capacity renewed generation and flexible energy storage, keeping the system in position as a cost — effective and integrated solution for clean energy deployment over the long term.

The overall system LCOE is calculated at 0.131 €/kWh, representing the average cost of generating one kWh of electricity over the system's entire operational lifetime. The project lifetime is assumed to be 25 years. Figure 12 includes capital investment, operational and maintenance expenses, energy losses, and component degradation across wind turbines, batteries, and conversion systems. An LCOE of 0.131 €/kWh reflects a balanced trade-off between storage integration and renewable generation, making the system economically viable for hybrid energy applications focusing on flexibility and stability.

Figure 12: Cost summary of combination 2



1.1.3. Comparison of Combination 1 and Combination 2

Both configurations are technically viable and fulfil the purpose of providing renewable energy without grid exports, but their economic outputs vary greatly. The PV + battery system provides slightly higher energy production and prolonged autonomy, but at significantly higher cost and low efficiency. Conversely, the wind + battery system displays better cost defence, high-capacity factor, and low storage requirements, making it a more attractive solution where wind resources are favourable.

Table 4: Results overview of combination 1 and 2

Parameter	Combination 1 (PV + Battery)	Combination 2 (Wind + Battery)
Annual Energy Generation (kWh)	62,777,186	58,500,266
Capacity Factor (%)	12%	47.70%
Excess Electricity (kWh/year)	40,503,999	37,439,326
Unmet Load (kWh/year)	13,274	15,993
Capacity Shortage (kWh/year)	17,693	19,969
Battery Strings	72	24
Battery Autonomy (hours)	132	44
Battery Round-Trip Efficiency (%)	~91%	~90%
Converter Rating (kW)	9,458	2,976
Converter Efficiency (%)	~95%	~95%
Total Lifetime Cost (€million)	146	46.2
LCOE (€/kWh)	0.412	0.131

2. Solar PV Capacity Estimation Based on Available Area

As a part of the overall feasibility analysis, it is essential to evaluate not only how much solar/wind capacity is required to meet the facility's energy demand, but also how much can realistically be installed on-site. Although the technical simulation identified the total solar and wind abilities required to complete the demand requirement of the facility, stakeholders requested the assessment of the real installed capacity within the available physical area of the facility. This ensures that the proposed renewable energy solutions are based on energy performance and spatial feasibility.

The total available area within the facility limit is about 8,712 m². Depending on site characteristics and spatial boundaries, only solar PV installation is possible within this region. While wind energy was considered in the broader system simulation, practical implementation of wind turbines, especially on a utility scale, is not viable on the site due to adequate land requirements, safety approval, and structural obstacles.

For example, a specific 2 MW wind turbines, such as Leitwind 90 used in simulation, require space not only for the physical footprint of the turbine, but also adequate approval for rotor diameter, turbulence mitigation, security areas and maintenance access. To operate efficiently and avoid interference with airflows, the turbine must be spread to about seven rotor diameters and three diameters from the edges. Leitwind 90, which has a 90-meter rotor diameter, is equivalent to a required area of about 630 meters by 270 meters, or is equal to 170,100 square meters, or about 42 acres per turbine.[12] Given that the total available site area is only 8,712 m², accommodating a 2 MW wind turbine on-site is physically and operationally unfeasible.

Therefore, while wind energy remains a technical and economically viable option in the broader system model (e.g., through off-site installation), solar PV is the only renewable energy technology that can be installed directly within the available land and roof area of convenience. This section estimates the total solar PV capacity that can be installed on a site with a usable area of 8,712 m2. The analysis assumes the use of standard 405-watt solar panels, which are usually used in installations on a utility-scale due to their efficiency and availability.

Each 405W panel typically measures 195 cm by 99 cm, equating to a surface area of approximately 1.9305 m².[13] To generate 1 kW of solar capacity, approximately 2.47 of these panels are required. Therefore, the area needed to install 1 kW of capacity is:

$2.47 \times 1.9305 = 4.77$ m² per kW

Given the total available area of 8,712 m², the theoretical maximum solar capacity assuming panels are installed in a tight layout without spacing for shading, access, or tilt is:

8,7124.77≈1,826 kW (or 1.83 MW)

The available land area of 8,712 m² [14] can theoretically support up to 1.83 MW of solar PV capacity using 405W panels under ideal layout conditions. However, when accounting for necessary spacing, the practical installable capacity might be smaller, depending on the installation configuration.

2.1. Electricity Modelling Results: Feasible Energy Solutions

The results focus on two primary technology combinations: Combination 1 – PV + Grid and Combination 2 – PV + Battery + Grid. The microgrid facility has a daily energy demand of 55,164 kWh and a peak load of 2,819 kW. It is important to note that no excess electricity produced by the renewable system is exported to the grid; the facility is only permitted to purchase electricity from the grid during periods of load shortage**.** The following sections present the performance results for each configuration in meeting the facility's energy requirements.

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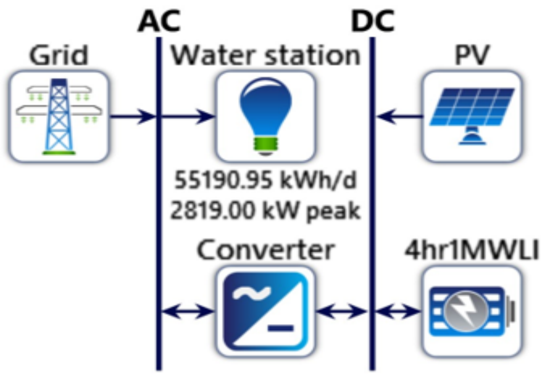
[12] https://todayshomeowner.com/eco-friendly/guides/how-much-space-does-a-wind-turbine-need/

[13] https://www.greenmatch.co.uk/solar-energy/solar-panels/sises

[14] Data received from water facility from WP2 survey

Figure 13: Design of a feasible hybrid energy system for optimisation



Source: Homer Pro

2.1.1. Feasible solution 1 – Solar PV + Grid

This section presents the performance outcomes of the first feasible system configuration: a hybrid energy solution combining PV generation with grid connectivity. This setup was selected to evaluate the potential of solar energy as the primary generation source, supported by grid power during periods of insufficient solar output. Unlike the battery-based configuration, the system receives the grid as a flexible backup, which still eliminates the option for on-site storage while maintaining the supply reliability. To optimise grid procurement and energy removal, HOMER Pro solar generation balances system performance with cost-effectiveness. In many configurations analysed, this solution was identified as a practical and economically attractive alternative, especially where grid access is available and storage is not preferred. The following analysis highlights the energy production of the system, dependence on grid imports, load coverage, curtailment and overall economic viability.

Table 5: Feasible solution 1 of a required capacity

Component	Name	Size	Unit
PV	Generic flat plate PV	1,827	kW
System converter	System Converter	715	kW
Grid	Grid	999,999	kW

The generic flat plate PV system provides frequent renewable energy production with a total rated capacity of 1,827 kW. It operates with an average output of 221 kW, which attains a capacity factor of 12.1%, specific to solar systems located in areas with moderate solar radiation. The system produces an average of 5,302 kWh per day, resulting in the total annual power generation of 1,935,230 kWh. The PV system works for about 4,379 hours per year, with a minimum output of 0 kW during the night, and maximum production at 1,835 kW under the position of the full sun. The PV entry rate is 9.61%, indicating that the solar system meets a minor part of the total energy demand; the remaining grid is supplied through purchase. In terms of the contribution of the overall system, the PV array is 9.4% of the total energy production, while the grid purchases the remaining 90.6%, which highlights the role of the PV system as a supplement to renewable sources rather than the primary energy supplier. The system supports AC load consumption of 20,144,697 kWh/year, and it operates without any unmet electric load or lack of capacity to ensure complete supply reliability.

Despite its moderate contribution, the system still generates 374,124 kWh of additional power per year, which indicates surplus production during low-demand or peak radiation hours. This excess can be exported, exposed or stored based on the system configuration. Although no energy clipping was recorded, it shows that the system was well added to the inverter and demand profiles. The LCOE is €0.0741/kWh, which is aligned with standard solar economics for PV systems on utility-scale. This cost reflects capital investment, maintenance, and performance during the system's lifetime and confirms the economic feasibility of solar integration even at low penetration levels.

Figure 14: Feasible solution 1 - Annual PV output

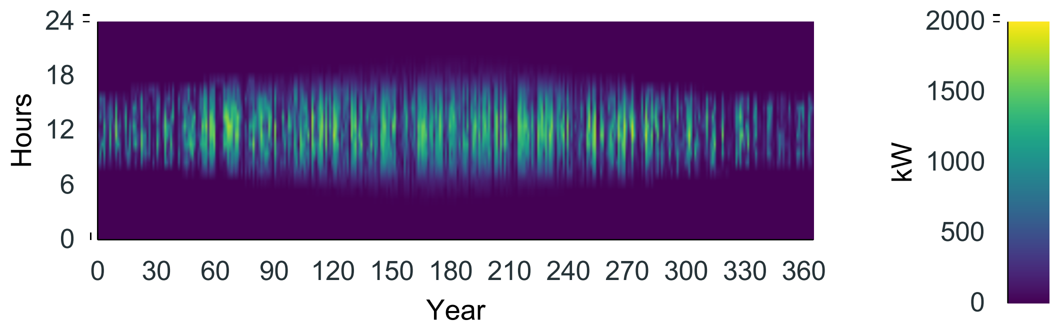


Table 6: Feasible solution 1 - Grid results

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge
January	1,694,746	0	1,694,746	2,789	€143,170
February	1,512,227	0	1,512,227	2,808	€116,737
March	1,564,400	0	1,564,400	2,780	€113,606
April	1,406,548	0	1,406,548	2,566	€109,256
May	1,433,317	0	1,433,317	2,523	€143,148
June	1,417,886	0	1,417,886	2,494	€176,781
July	1,536,352	0	1,536,352	2,528	€212,601
August	1,613,327	0	1,613,327	2,636	€219,886

September	1,553,820	0	1,553,820	2,636	€209,701
October	1,599,144	0	1,599,144	2,563	€208,515
November	1,615,730	0	1,615,730	2,588	€209,777

The system converter is designed with a rated power capacity of 715 kW and operates with an average production of 169 kW, resulting in a capacity of 23.7%. This refers to aligned moderate but stable use in the hybrid system with specific energy transfer demands. The converter operates for 4,379 hours per year, processes the total energy input of 1,561,106 kWh and distributes 1,483,050 kWh of useful energy production. The system experiences a conversion deficit of 78,055 kWh/year, responsible for about 5% energy input, which is in line with standard efficiency expectations for high-quality power electronics. The converter handles a full power range from 0 kW to 715 kW, which provides flexibility for ramping load, intermittent renewable input and battery charge/discharge cycles. This adaptability is essential for grid stability and real-time energy balance.

Figure 15: Feasible solution 1 - System converter inverter output (kW)

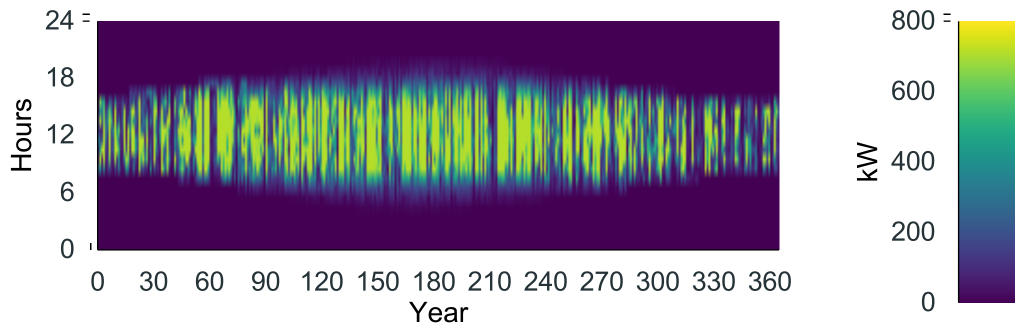
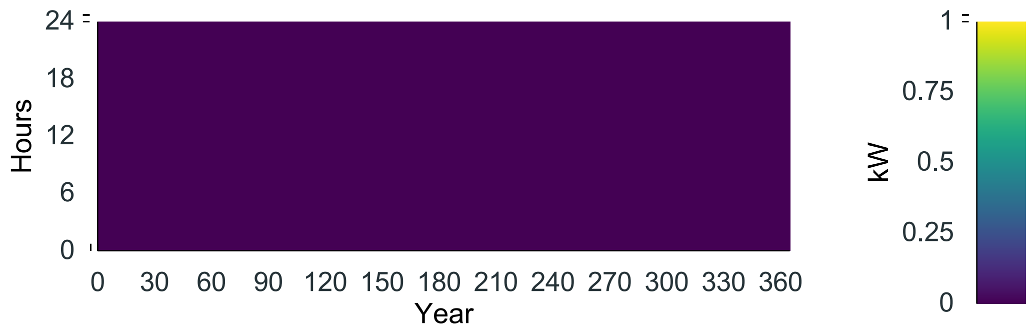


Figure 16: Feasible solution 1 - System converter rectifier output (kW)

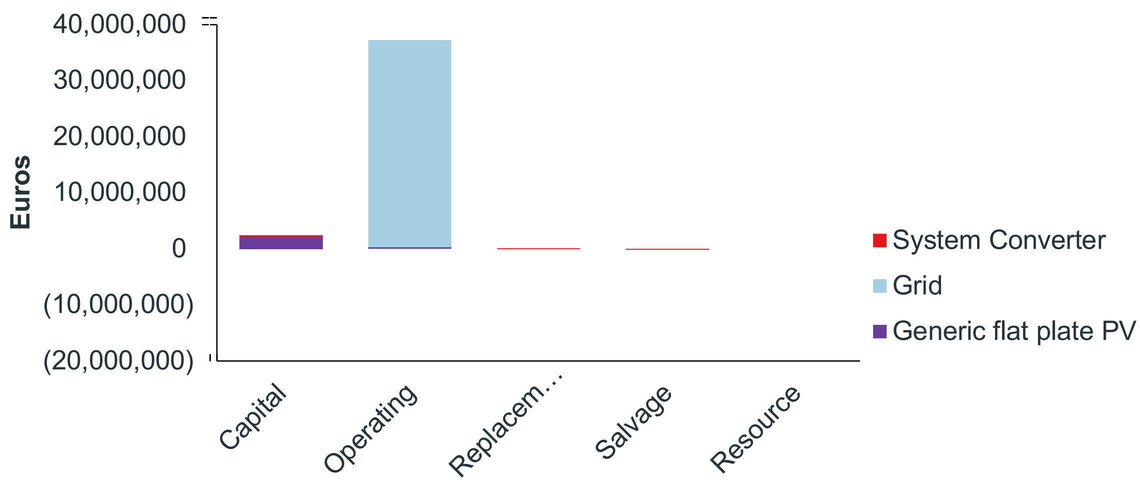


The total lifetime cost of this hybrid energy system is €39.8 million, including capital investment, operational expenditure, component replacement, and the disposal cost over the lifetime of the 25-year project. The generic flat plate PV system contributes €2.51 million to the total cost, including a capital investment of €2.19 million and €320,316 in operating expenses. With no replacement or salvage costs, the PV system represents a low-maintenance, prolonged-life property that provides clean, renewable energy and reduces dependence on grid power.

The grid acts as a primary energy source in this configuration, accounting for €37.0 million in operating expenditure on the life of the system. This cost reflects the continuous purchase of electricity from the central grid without capital or replacement costs. While it simplifies infrastructure and ensures reliability, it also requires high long-term operations and limits energy self-sufficiency.

The system converter responsible for managing energy flow between the PV array and the AC load increases the total cost of €318,812. This includes €214,559 in capital investment, replacement cost of €138,902, and negative salvage value of €34,650, representing the estimated decommissioning and settlement expenses. Despite its relatively small cost stake, the converter plays an important role in integrating the renewable generation and ensuring stable power distribution.

Table 71: Feasible solution 1 of a cost summary



Overall, the financial breakdown of the system includes €2.41 million in capital costs, €37.3 million in operating expenses and €138,902 in replacement costs, with a slight negative salvage adjustment of €34,650. This breakdown highlights that while the solar PV system combines long-term stability benefits with minimum cost, the grid remains the primary cost driver, mainly due to the ongoing energy purchase. The resulting LCOE is €0.113/kWh, indicating a moderate-cost solution favouring simplicity and reliability on complete energy freedom. Overall, the system represents a grid-dominant hybrid model complemented by solar PV and is managed through a converter, providing moderate stability benefits with a strong dependence on the purchased power.

2.1.2. Feasible Solution 2 – Solar PV + Battery + Grid

This section presents the performance results of the second feasible system configuration: a hybrid energy solution that integrates solar PV generation, battery storage and grid connectivity. This setup was selected to evaluate the effectiveness of a combination of renewable generation on the site with both storage and grid backup, enabling more energy freedom and operational flexibility. Unlike configurations that perfectly rely on grid or storage, this system uses the battery to store excess solar energy and smooth the supply. HOMER Pro optimises interactions between solar generation, battery dispatch and grid imports, focusing on balanced reliability, stability and cost-optimality. This configuration was identified as a flexible and well-rounded solution among the analysed scenarios. The following analysis includes system's generation profiles, storage utilisation, grid reliance, current levels and overall economic performance.

Table 8: Feasible solution 2 - Required capacity

Component	Name	Size	Unit
PV	Generic flat plate PV	1,769	kW
Storage	Generic 4hr 1MW Li-Ion	1	strings
System converter	System Converter	1,124	kW
Grid	Grid	999,999	kW

The generic flat plate PV system is an engineer to supply renewable power supplemented with a rated capacity of 1,769 kW. It operates on an average production of 214 kW to suit an average daily production of 5,131 kWh/day. The system provides annual energy production of 1,872,996 kWh, resulting in a capacity factor of 12.1%, which corresponds to solar installations in moderate sunny locations.

The PV system is active for about 4,379 hours per year, with 0 kW (night/passive period) to a maximum of 1,776 kW during peak solar conditions. The PV penetration rate of 9.3% indicates that the solar system provides a small share of energy but consistent portion of the total energy requirements, with the majority of around 90.7% still received from the grid purchase. As stated, the PV system does not have any clip production experience, confirming that the inverter capacity corresponds well for the generation's capacity. The LCOE is €0.0741/kwh, when economic viability for long-term solar generations is performed compared to grid-purchased power.

In the context of the total system generation, the PV system contributes 9.25% of the total 20,240,524 kWh/year supplied to the load. While the percentage is modest in terms of percentage, this renewable contribution helps reduce operating emissions and offset a portion of the grid dependence of the system.

Figure 17: Feasible solution 2 - Annual PV output

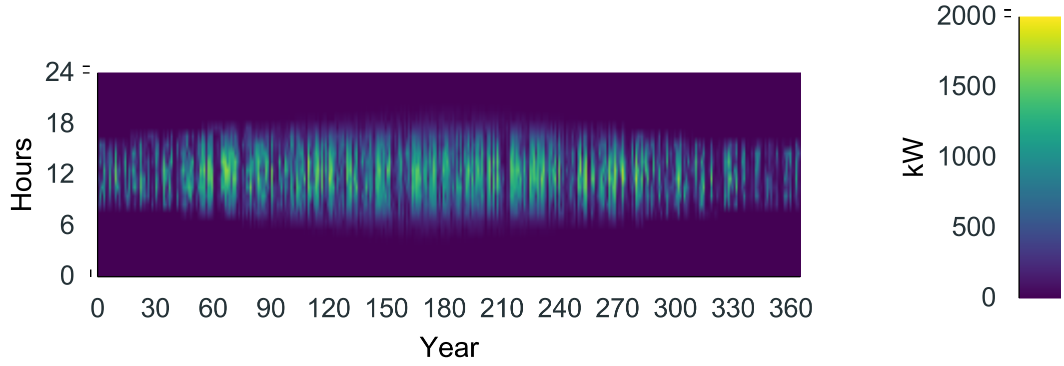


Table 9: Feasible solution 2 - Grid results

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge
January	1,680,317	0	1,680,317	2,789	€141,982
February	1,489,734	0	1,489,734	2,808	€115,457
March	1,529,835	0	1,529,835	2,782	€111,783
April	1,378,701	0	1,378,701	2,568	€107,389
May	1,402,374	0	1,402,374	2,524	€141,429
June	1,389,778	0	1,389,778	2,497	€175,286
July	1,505,576	0	1,505,576	2,528	€210,463
August	1,574,022	0	1,574,022	2,636	€217,198
September	1,520,734	0	1,520,734	2,636	€206,861
October	1,580,213	0	1,580,213	2,563	€206,373
November	1,603,657	0	1,603,657	2,588	€208,590
December	1,712,589	0	1,712,589	2,791	€245,887
Annual	**18,367,528**	**0**	**18,367,528**	**2,808**	**€2.09M**

The generic 4-hour 1 MW Li-ion represents a compact storage solution manufactured from a single battery unit, which is rated at a nominal and usable capacity of 4,216 kWh. Working on a 600 voltage, this system supports short-term energy storage applications with a discharge autonomy of about 1.83 hours on full output.

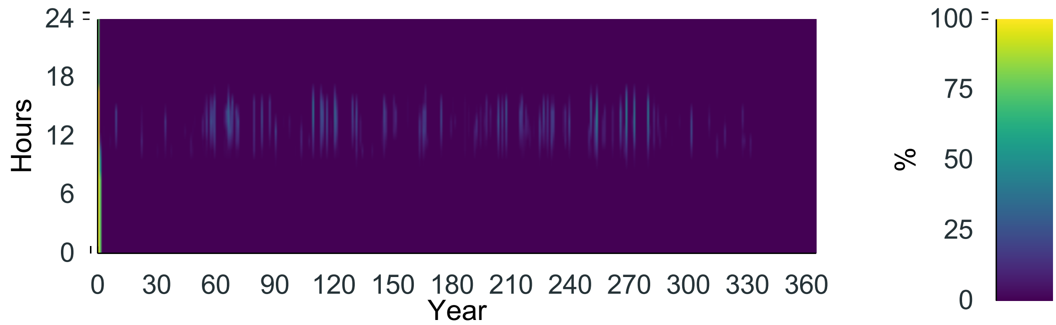
The system handles 62,910 kWh of energy input per year, delivering 60,619 kWh of useful output, with a total annual throughput of 63,898 kWh. Losses are reported at

6,507 kWh/year, and storage depletion energy, irreversibly lost due to degradation, is 4,216 kWh/year, typical for Li-ion chemistry under light to moderate cycling.

EFCs estimate per year is 15.2, or 0.0415 cycles per day, indicating that the battery is low on cycles and the possibility of operating in a standby, backup, or low-existence remittance role. This low cycling intensity expands the battery life while maintaining availability for important support functions.

With a lifetime throughput capacity of 958,472 kWh and a storage wear cost of €0.025/kWh, the battery system balances longevity and economic efficiency. Although the average energy cost is 0€/kWh, likely reflecting renewable charging, degradation, and replacement remain important cost considerations over the system's 15-year expected life.

Figure 18: Feasible solution 1 – Battery storage output



The system with a rated capacity of 1,124 kW maintains an average production of 203 kW, resulting in a capacity of 18.0%. This variable indicates aligned moderate use with renewable input and load demands. While working 6,319 hours per year, the converter processes 1,870,705 kWh of input energy, providing 1,777,169 kWh of usable energy after conversion. Energy loss is 93,535 kWh/year, corresponding to about 5% of the energy input, a display benchmark to suit industry standards for high-efficiency power electronic systems. From 0 kW to 1,124 kW with full output range, the converter displays excellent flexibility, allowing it to send energy from rapid ups and downs in electric current and from storage or renewable sources, which is grid or load as required.

Figure 19: Feasible solution 2 - System converter inverter output (kW)

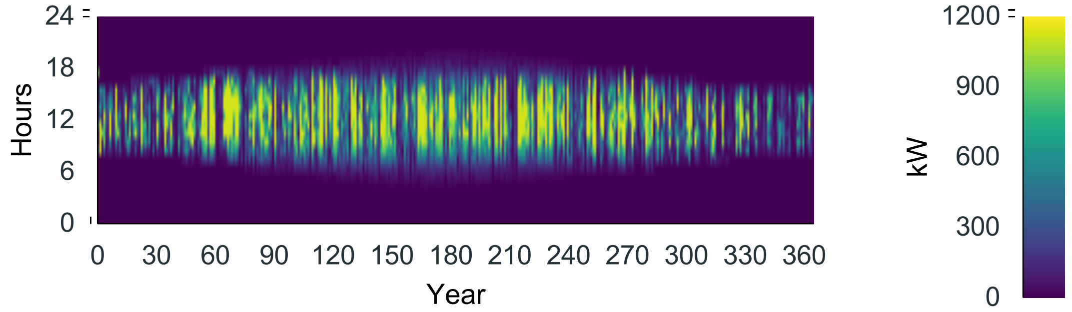
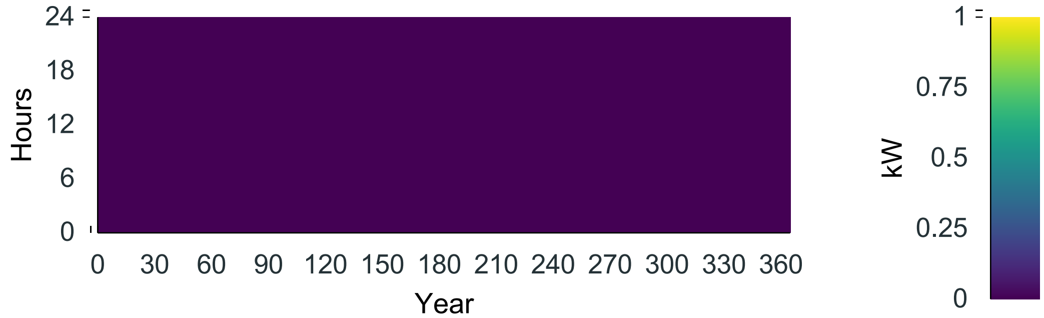


Figure 20: Feasible solution 2 - System converter rectifier output (kW)



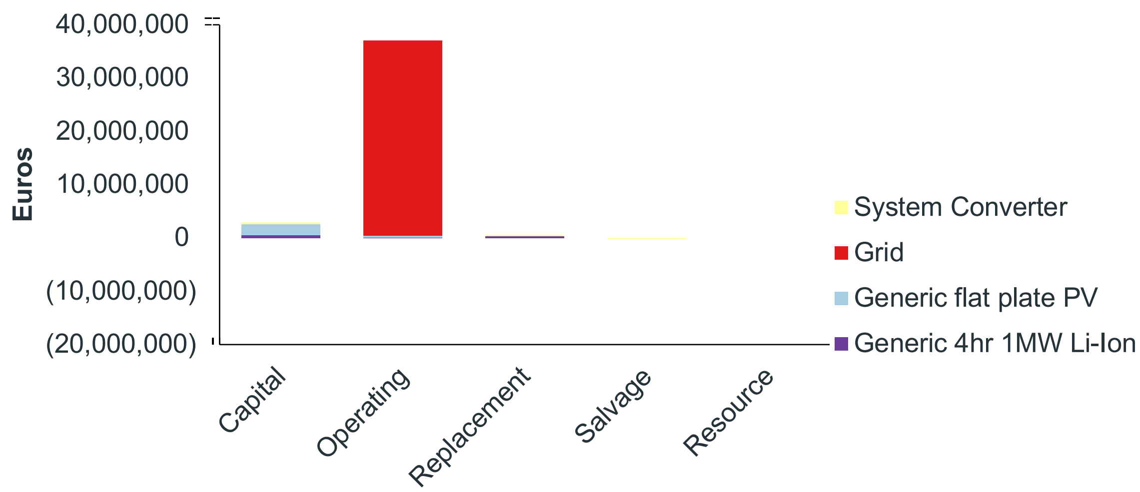
The total lifetime cost of this hybrid energy system is estimated at €40.4 million, covering capital expenditure, operational costs, replacement requirements, and salvage values of life. The system integrates four major components: a lithium-ion battery storage unit, a flat plate PV array, grid power purchase and a system converter.

The Generic 4-hour 1 MW Li-Ion battery storage system contributes €830,586. This includes €500,000 in capital investment, €87,639 in operating costs, and €323,693 in replacement expenses, partially offset by a negative salvage value of €80,746 for decommissioning and disposal. This compact battery solution supports peak shaving, energy shifting, and reliability during variable load conditions.

The Generic Flat Plate PV System costs €2.43 million over its lifecycle. This figure includes capital costs of €2.12 million and operating expenses of €310,015. There are no replacement or disposal costs, a long service life, and a specific profile for solar property with low maintenance requirements. The PV system provides clean, renewable electricity at a competitive cost, which contributes to reducing grid Dependence.

The grid represents major operating expenses at €36.6 million, reflecting the high cost of procurement of infrastructure-free, long-term power in terms of capital investment. This highlights a dependence on external power sources and significantly shapes the system's overall cost structure. The system converter, required to integrate PV and battery storage with AC load, contributes €501,184 in total costs. This includes €337,295 in capital investment, €218,360 for replacement and negative salvage costs of €54,470. Despite its low-cost stake, the converter is important in managing bidirectional and ensuring system interpretation.

Figure 21: Feasible solution 2 cost summary



Overall, the system includes €2.96 million in capital costs, €37.0 million in operating costs, €542,053 in replacement expenses and €135,216 in disposal-related costs, for a total lifetime cost of €40.4 million. While grid energy dominates long-term expenditure, incorporating solar PV and battery storage has significant energy autonomy and stability benefits. This balanced configuration results in the LCOE of €0.114/kWh, which reflects a cost-effective yet flexible approach to hybrid energy management.

2.1.3. Comparison of feasible solutions 1 and 2

Table 10: Comparing feasible solutions

Parameter	Solution 1: PV + Grid	Solution 2: PV + Battery + Grid
PV Capacity	1,827 kW	1,769 kW
Battery Storage	None	1 string (4.2 MWh)
Grid Dependency	90.60%	90.70%
PV Contribution to Load	9.40%	9.25%
Battery Contribution	–	Standby/Support
Total Lifetime Cost	€39.8 million	€40.4 million
Capital Costs	€2.41 million	€2.96 million
Operational Costs	€37.3 million	€37.0 million
LCOE	€0.113/kWh	€0.114/kWh

Both configurations are technically viable and economically competitive. Solution 1 (PV + grid) is simple and slightly more cost-effective, reliable grid access and ideal for features with no backup requirements. Conversely, solution 2 (PV + battery + grid) provides maximum energy flexibility, which makes this energy better suited for sites that prefer autonomy or backup capacity. The enhancement of the future system may include expanding battery storage or an increase in PV capacity to reduce grid reliance and improve long-term stability.

3. Heating Technologies Solutions

A detailed technical assessment was made to evaluate the viability and performance of three different heat pump configurations: water-to-water heat pump (WWHP), Air-to-Water Heat Pump (AWHP), and Air-to-air heat pump (AAHP). The primary objective was to determine the most efficient and appropriate system capable of completing the fixed annual thermal load of the station, which is counted at 3,059,588 kWh. In contrast, operating criteria such as the annual runtime, electrical energy input, essential thermal capacity, and the ability to handle the thermal load are also considered. The analysis considers 4,368 operating hours per year, reflecting continuous seasonal heating operations.

The WWHP, with the highest coefficient of performance (COP) of 5.5[15], is the most energy-efficient and economical option. Its CAPEX is €207,971, covering system procurement, installation, and infrastructure such as a borehole or water source connection. Fixed OPEX is €4,159, while variable costs, reflecting annual energy consumption, are €77,880—significantly lower than the alternatives due to reduced electrical demand. The total annual cost is €290,011, making it the most cost-effective system for continuous operation.

The AWHP requires a higher initial investment of €229,924, partly due to its larger unit size and air-side components. OPEX is €4,598, but its lower COP of 4.0[15] increases electricity use, resulting in a variable cost of €107,086. This brings the total to €341,608, more than the WWHP.

The AAHP, with the lowest COP of 3.5[15] and limited compatibility with hydronic infrastructure, has a lower CAPEX of €211,537 and OPEX of €4,231. However, its high electricity demand pushes variable costs to €122,384 annually, leading to a total of €338,152, which is slightly less than the AWHP but far above the WWHP.

When technical performance and financial outcomes are considered together, the WWHP emerges as the optimal choice. Despite higher installation requirements, its

[15] https://www.ariston.com/en-me/the-comfort-way/news/coefficient-of-performance-of-a-heat-pump-what-is-it/

superior efficiency, lowest total cost of ownership, and long-term operational savings make it the most durable and economically sound heating solution for the station.

Table 11: Technical background of heat pumps

System	COP	Annual Thermal Load (kWh)	Heat pump load (kWh)	Required Capacity (kW)
Water-to-Water HP	5.5	3059588	556289	127
Air-to-Water HP	4	3059588	764897	175
Air-to-Air HP	3.5	3059588	874168	200

3.1. Economic Analysis of Heat Pump Technologies

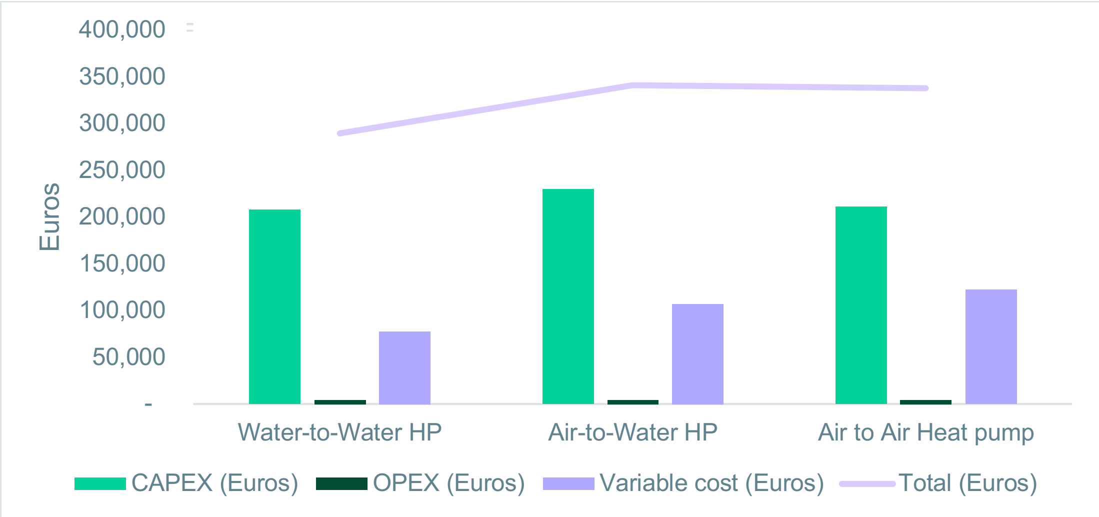
A detailed economic analysis was performed to complement the technical performance evaluation of the heat pump system at the selected water supply station. This analysis considered transformed costs associated with capital expenditure (CAPEX), Operating Expenditure (OPEX), and operating three systems: the WWHP, AWHP, and the AAHP. These economic indicators provide significant insights into the long-term financial implications of each technology and support the selection of the most cost-effective and efficient system.

The Water-water heat pump, which was identified as the most energy-efficient option due to the high coefficient of performance of COP 5.5, is also the most economical in total annual costs. CAPEX for this system is calculated at €207,971, which reflects the necessary investment for the system procurement and installation, including the required infrastructure such as a borehole or water source access. Fixed OPEX, a regular maintenance and system covering service, is relatively low at €4,159. Meanwhile, the convertible cost, which significantly reflects the annual energy consumption, is €77,880, much lower than the other two systems due to the system's high energy efficiency and low electrical demand. This resulted in a total annual cost of €290,011, making it the most economically favorable option for continuous operation at the station.

In comparison, the Air-to-Water Heat Pump requires a higher initial investment with a CAPEX of €229,924. It partially integrates a large unit size and an air-side coil or defrost system. OPEX is slightly higher than the water-water systems at €4,598. However, where the air-to-water HP is financially underperforming, it is in its variable cost, which is €107,086. This directly results from the lower COP 4.0, requiring much more electrical energy to meet the same thermal demand. Therefore, the total cost of this system is calculated at €341,608, which is more expensive than €51,597 water-based counterparts. During AWHP on €211,537, the air-to-air heat pump is less capital-intensive, reduced due to a relatively low COP of 3.5, and has limited suitability for hydronic infrastructure. It has a fixed OPEX of €4,231, which is modest, but its variable cost is the highest of the three systems, totaling €122,384 annually. This elevated variable cost is a direct consequence of the high electrical consumption required to compensate for the low efficiency of the system. The total annual cost of the AAHP is €338,152, which is slightly lower than the air-to-water system, but still much higher than the water-to-water system.

Finally, when both technical performance and financial effects are considered simultaneously, the water-to-water pump is the optimal option for the water supply station. This not only displays the lowest electrical demand and the highest energy efficiency, but it also results in the lowest total cost of ownership when accounting for capital, operational, and variable expenses. Although it requires a high degree of infrastructure development during installation, energy savings and low running costs over time are defeated mainly by early investment, making it the most durable and economically sound solution for the station's heating requirements.

Figure 22: Cost summary of heat pumps



3.2. Analysis of Required Solar Technology for Heat Pumps

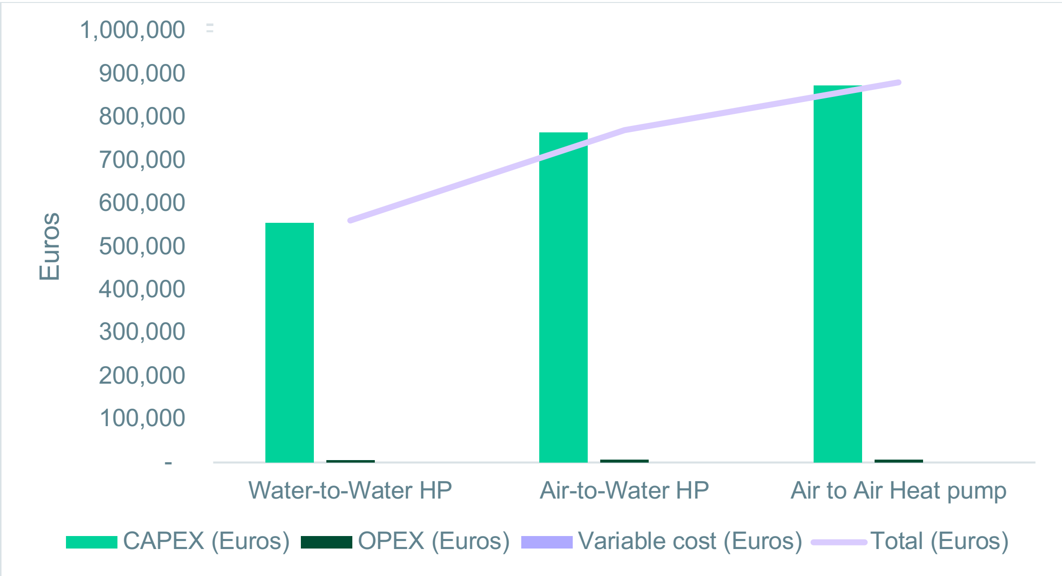
To provide a complete economic and technical perspective for the selected water supply station, the financial impact of integrating solar technologies to cover the electricity requirements of the heat pump systems has also been evaluated. This analysis considers the required CAPEX, OPEX, and the total cost for solar systems designed to meet the complete electrical demand for each related heat pump configuration: Water-to-Water, Air-to-Water, and Air-to-Air.

The WWHP, with the lowest annual energy use of 556,289 kWh, requires a solar CAPEX of €556,289 and an annual OPEX of €4,636. With no variable energy costs, the total investment is €560,924, making it the most cost-effective option. The AWHP, consuming 764,897 kWh annually due to its lower COP, requires €764,897 in CAPEX and €6,374 in annual OPEX, bringing the total to €771,271. The AAHP has the highest demand—

874,168 kWh/year, linked to a COP of 3.5, resulting in €874,168 CAPEX and €7,285 OPEX, for a total of €881,453. This makes it the most expensive and least efficient choice under full solar operation.

Overall, WWHP's low energy demand allows for a smaller, more affordable PV system, while AAHP's high demand necessitates the largest and most costly system. For a shift toward renewable, self-sufficient energy, the WWHP is both the technically and economically optimal solution for the station.

Figure 23: Cost of solar PV required for heat pumps



3.3. Techno-economic analysis of Heat Pump+Solar PV technologies

To finalise the extensive technical-economic evaluation of the heat pump system at the selected water supply station, the total joint cost of each heat pump system integrated with the required solar PV infrastructure has been compiled. These values represent the cumulative investment required for both the heating systems (including CAPEX, OPEX, and Variable Energy Costs) and the renewable energy components designed to meet the electrical demands of the system.

The WWHP, with the highest COP and lowest energy consumption, remains the most cost-effective option when paired with solar PV, with a total system cost of €850,936. Its modest electrical demand allows for a smaller and more affordable PV array, reducing overall investment while enabling fully renewable, self-sufficient operation.

The AWHP's lower COP drives its total cost up to €1,112,880, as the larger PV system required to meet its higher energy demand significantly increases capital costs. The

AAHP, with the lowest COP and highest energy consumption, reaches €1,219,604, requiring the largest PV installation and offering poor compatibility with water-based heating infrastructure, making it the least suitable and most expensive choice for this application.

Overall, the integrated cost analysis reinforces WWHP as the optimal solution, combining high efficiency, long-term operating savings, and the lowest total system cost when renewable energy is included. It offers the most technically and economically robust pathway to reliable, low-carbon heating for the station.

Table 12: Overall cost of PV and heat pumps

Systems	Cost HP+PV in Euros
Water-to-Water HP	850,936
Air-to-Water HP	1,112,880
Air-to-Air Heat Pump	1,219,604

3.4. Summary of Heating Technology Solutions

Selecting a suitable heating technology should consider energy efficiency, operating reliability, and the site's physical obstacles. The total available area in this feature is only 8,712 m2, which imposes significant boundaries on the possible types of systems that can be established. In particular, large-scale combined heat and electricity (CHP) plants, which usually require enough space for an engine, fuel storage, heat recovery units and supporting systems, are unsuitable for this location. CHP installations also include complex infrastructure for fuel supply and exit management, increasing their spatial demands. High-capacity biomass or gas-powered boilers face similar challenges, requiring large footprints for equipment and fuel handling and strict environmental permissions. Given these limitations, decentralised and compact heating techniques, such as heat pump systems, especially those that can be integrated with roof or limited-field PV arrays, offer a more practical and spatially compatible solution. Heat pumps, particularly the water-to-water type, offer high energy efficiency while maintaining a compact system footprint, making them ideally suited for deployment at sites here land availability is restricted.

In conclusion, the selected water supply station can achieve high-efficiency, low-carbon heating through the implementation of a appropriate Heat Pump solution. While a 1.83 MW solar PV system installed on the available 8,712 m² of site area generates enough electricity to fully cover the heat pump's needs in theory, this entire PV capacity is already allocated to general facility operations and offsets only around 9.6% of the total site demand. As no additional space is available for new PV, the heat pump cannot be powered exclusively by dedicated on-site solar. However, based on an hourly load profile and solar generation pattern, a part of the power consumption of the heat pump can still be covered by additional PV output when it coincides with a demand for low convenience. The grid should

supply the remaining electricity for heating and normal operations or be sourced by off-site renewal. To reduce the dependence on grid power and improve energy autonomy, off-site renewable development, energy storage integration and load optimisation in future strategies should align renewable availability with better demand.

WP5 - Mapping of Financing Opportunities

The selected water supply station is a critical public utility, as it provides a wide range of services related to the quality water supply and sewage system for around 400,000 people. It is a strategic candidate for installation of renewable energy solutions, as ensuring uninterrupted water supply and wastewater treatment requires resilient, energy-efficient systems. The estimated cost for the solar power solution for the selected water supply station is approximately €2.5 - 3.5 million, depending on the technological solution chosen to be installed within the available area. WP5 aims to provide a comprehensive overview of potential financing opportunities from international financial institutions and other relevant sources to support the installation of renewable technologies such as solar PV and battery storage.

To enable the installation of the renewable power solution, it is necessary to find optimal financing opportunities. In 2025, multiple international and national programs are available to support municipal renewable energy projects in Ukraine. However, each of them comes with unique opportunities and limitations, making it crucial to analyse these programs to determine the most suitable combination of financing sources and actionable steps that the municipality can take towards financing the renewable energy solution for the water station.

The financing of municipal renewable energy projects in Ukraine can be organised by combining several international financing tools, including grants, loans, guarantees and technical assistance.

Table 13: International financing tools

Grants	A financial aid given **to cover part or all of the costs** associated with planning, purchasing, or installing renewable energy equipment, **without the obligation to repay** the funds. Can support de-risking loans.
Loans	A sum of money borrowed from a commercial bank, development bank, or international financial institution under agreed terms — **typically involving interest, a repayment schedule, and sometimes guarantees**.
Guarantees	**A financial commitment** by an institution (such as a development bank, donor program, or national guarantee fund)

	to cover part or all of a lender's loss if the borrower defaults on a loan.
Technical Assistance	**Expert support offered to help with the design, feasibility, procurement, implementation, or monitoring of a renewable energy project** (e.g., solar installation) — typically funded by a donor and not repayable.

This chapter will explore renewable energy technology financing tools provided by various international financial organisations (IFIs), funds, and development banks suitable for the selected object. The report recommends considering the following opportunities for financing the installation of renewable energy technology at the selected water supply station.

1. European Bank for Reconstruction and Development (EBRD)

EBRD has demonstrated a strong and unwavering commitment to supporting Ukraine during the ongoing military invasion. Between the beginning of the full-scale invasion of the Russian Federation against Ukraine in February 2022 and the end of 2024, EBRD deployed more than €7 billion to Ukraine to support the country's economy and infrastructure. EBRD's further commitment is evidenced by the approval of a €4 billion increase in its paid-in capital in 2025.[16]

EBRD's strategy for Ukraine is bolstering energy security, supporting vital infrastructure, and facilitating the country's green transition. The EBRD's aim to invest €1 billion into its energy programs in 2025 further highlights its capacity to support a project of this nature.[17] The institution provides a range of financing tools to support projects in Ukraine, including loans that can be tailored to the specific requirements of the renewable energy installation. They also offer equity investments, typically taking a minority stake, and various guarantee instruments, such as portfolio risk-sharing facilities, which can enhance the creditworthiness of borrowers.

The heightened need for resilient energy solutions for critical utilities and the sheer scale of EBRD's financial commitment and its strategic prioritisation of Ukraine's energy sector in the face of the invasion position it as a primary avenue to explore funding options for installation of renewable energy technology at the selected water supply station. The EBRD's lending activities in wartime Ukraine are guided by its Resilience and Livelihoods Framework, which identifies energy security and vital infrastructure as core

[16] https://www.ebrd.com/home/what-we-do/where-we-invest/ukraine.html

[17] https://www.power-technology.com/news/ebrd-support-ukraine-energy-sector-2025/

priorities.[18] Recognizing the vulnerability of centralised energy infrastructure in Ukraine, the EBRD is supporting projects that promote the decentralisation of energy production and increase the share of renewable energy sources in Ukraine's overall energy mix, which currently stands at around 10%.[19] This strategic focus on expanding renewable energy capacity directly addresses the water supply station's need for a renewable energy solution. The EBRD's proactive approach in this sector significantly enhances the potential for securing funding for a well-structured solar project.

The urgency of Ukraine's energy situation, exacerbated by the ongoing attacks on infrastructure, has likely led to a more streamlined approach to funding processes at the EBRD, making timely engagement of paramount importance. The EBRD's strategic emphasis on both enhancing energy security and facilitating the green transition creates a strong alignment for a renewable energy project that will bolster the resilience of critical water infrastructure. Moreover, the EBRD offers technical assistance that can complement WP3 and WP4 of this project, provide invaluable support in navigating EBRD’s own financing mechanism, and support preparation of required documentation. The European Union's backing through the UIF further strengthens the EBRD's capacity and risk appetite for supporting energy projects in Ukraine, providing loans and guarantees that can significantly de-risk investments for installation of renewable energy technologies.

EBRD’s municipal loans typically range from €7 million to €25 million, often paired with grants (e.g., E5P, EU Neighborhood Investment Platform), especially in the case of smaller (<€10m) projects. **Smaller-scale loans are rare as standalone funding; instead, they are usually structured as loans paired with grant funding, to improve affordability and reduce risk for both borrower and lender.** EBRD’s financial support to municipal renewable energy projects in Ukraine operates through several programmes (listed below).

1.1. EBRD's Energy Security Support Facility (ESSF)

A particularly promising avenue is the EBRD's Energy Security Support Facility (ESSF).[20] This dedicated programmeis designed to assist various borrowers, including small and medium-sized enterprises, municipalities, and state-owned companies, in investing in decentralised energy generation, renewable energy technologies, and energy efficiency measures.

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[18] https://www.ebrd.com/home/work-with-us/projects/psd/53662.html

[19] https://www.eqmagpro.com/ebrd-to-provide-1-billion-euros-to-ukraines-war-ravaged-energy-sector-in-2025-eq/

[20] https://www.ebrd.com/essf-ukraine

ESSF is a risk-sharing programmedesigned to enhance access to financing for energy security investments in Ukraine. **Under ESSF, the EBRD extends portfolio-risk-sharing guarantees to selected Ukrainian banks (i.e. PrivatBank, Ukrgasbank, Oschadbank, Raiffeisen Bank, ProCredit Bank and beyond), enabling them to offer loans for projects related to decentralised energy generation, energy storage, and energy efficiency.**[21]

ESSF prioritises projects that aim to bolster Ukraine's energy resilience, particularly in the face of the ongoing infrastructural challenges. The sub-loans provided by the national banks under the ESSF are intended for investments in energy generation, storage, and efficiency measures. At least 70% of the sub-loans must align with the EBRD’s Green Economy Transition approach. Additionally, **eligible borrowers may receive technical assistance for project preparation and implementation and, in some cases, post-investment grant support to facilitate the implementation of their projects.**[22]

The explicit eligibility of municipalities under the ESSF, coupled with its specific focus on enhancing energy security through renewable sources, positions it as one of significant potential financing sources to finance installation of renewable energy technologies. While the EBRD does not provide loans directly under the ESSF, it plays a crucial role in facilitating access to financing for energy security projects in Ukraine through its partnerships with local financial institutions. The programmeoffers €700 million in portfolio guarantees, as well as valuable technical assistance and investment incentives to support project implementation. Ukrainian municipal enterprises are eligible for financing under the ESSF, which specifically targets energy security investments.

1.2. EBRD’s Hi-Bar Programme

Another significant mechanism implemented by the EBRD with the EU support under the Ukraine Investment Framework (UIF) is the Hi-Bar Programme. The programme specifically targets climate mitigation technologies within the energy sector by offering crucial financial instruments like guarantees, which can help de-risk investments, and providing technical assistance for project development.[23] The EU's strong financial and political backing through the UIF amplifies the EBRD's capacity and willingness to

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[21] ebrd.com+11ukrgasbank.com+11ebrd.com+11support4partnership.org+10inventure.com.ua+10ebrd.com+10news.europawire.eu

[22] intranet.ebrd.com+11oschadbank.ua+11keyfactsenergy.com+11ewsdata.rightsindevelopment.org+6support4partnership.org+6support4partnership.org+6ebrd.com+2intranet.ebrd.com+2keyfactsenergy.com+2

[23] https://lewiatan.org/wp-content/uploads/2025/01/EBRD-in-Ukraine-UIF-Dec-24.pdf

support energy projects in Ukraine, making the Hi-Bar Programme a notable opportunity to secure investment guarantees for the water supply station.

The heart of the Hi-Bar programme is the **EU-backed financial guarantees, with a funding envelope of around €150 million. These guarantees de-risk investments in new and climate-smart energy technologies, such as renewable power, energy storage, and energy-efficient industrial projects.** [24] **Via these guarantees, the EBRD facilitates loans to eligible partners. Hi-Bar also includes approximately €7.5 million in technical assistance** aimed at supporting beneficiaries in preparing bankable projects and deploying clean energy solutions according to EU and international standards.[25]

1.3. The Municipal, Infrastructure & Industrial Resilience Guarantee Programme

The Municipal, Infrastructure & Industrial Resilience (UIF MIIR) guarantee also operates under UIF, aiming to address emergency support and long-term reconstruction needs across various sectors, including municipal infrastructure. The programme focuses on addressing both immediate and long-term needs of Ukraine's infrastructure and industrial sectors, which have been severely impacted by the ongoing conflict. By providing financial support and technical expertise, the programme aims to aid sustainable rebuilding, ensure continuity of essential services, and support municipalities in maintaining and restoring critical infrastructure such as water supply, waste management, and public transportation.[26] The UIF MIIR could be a relevant tool for financing of the renewable energy project at the selected water station.

UIF MIIR delivers a blended mix of financial instruments — guarantees, grants, and technical assistance. Namely, **€150 million financial guarantees** provided by the EU through UIF and under MIGA aim to help de-risk EBRD-financed municipal, infrastructure, and industrial projects in Ukraine, favouring private and institutional lending.

Grants under UIF MIIR aim to help improve project viability by covering part of the costs and making co-financing through the EBRD or other institutions more attractive. A separate contribution of **€25 million in investment grants** is made available to support eligible projects, enhancing their financial viability and encouraging private sector participation. Additionally, **€7.5 million is allocated for technical assistance**, offering

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[24] https://www.ebrd.com/home/news-and-events/news/2024/supporting-ukraine-with-517-million-of-eu-funding-through-ebrd.html

[25] international-partnerships.ec.europa.eu

[26] https://www.miga.org/sites/default/files/archive/Documents/06ar_Development_Impact.pdf

expertise and support to ensure the successful planning, implementation, and sustainability of projects.[27]

2. The European Investment Bank (EIB)

The EIB also has demonstrated a strong and consistent commitment to supporting Ukraine's resilience, economic stability, and recovery efforts, particularly focusing on the energy and infrastructure sectors. The scale of the EIB's support is substantial, with over €2.2 billion disbursed to Ukraine since 2022, and, in March 2025, the European Commission and EIB Group signed a guarantee agreement enabling the EIB to invest at least €2 billion in Ukraine under the Ukraine Facility.[28]

The Ukraine Facility is a major European Union financial support instrument created to help Ukraine recover, rebuild, and reform in response to Russia’s full-scale invasion. It is a €50 billion multi-year package (2024–2027) combining grants, loans, and guarantees, designed to support Ukraine's economic stability, reconstruction, and EU accession path. Many of EIB’s financing packages are channelled through the European Union's Ukraine Facility. These packages often include specific programs and initiatives, targeting critical infrastructure needs.[29] [30]

In addition to the Framework Loan (FL) programmes listed in the following sub-sections, the EIB provides guarantees under the EU's Ukraine Facility, which can enhance project financial viability. This includes risk-sharing instruments like the Ukrainian Guarantee, which covers financial risks and thus enables the EIB [and other IFIs] to commit large investments and issue loans to fund public infrastructure projects.[31] [32]

2.1. Ukraine Water Recovery Framework Loan

The EIB’s Ukraine Water Recovery FL was signed in February 2025 for approximately €100 million and is part of a broader €200 million infrastructure package for water and

[27] https://www.ebrd.com/home/news-and-events/news/2024/supporting-ukraine-with-517-million-of-eu-funding-through-ebrd.html

[28] https://www.eib.org/en/press/all/2025-180-eib-group-president-calvino-and-ukrainian-prime-minister-shmyhal-accelerate-support-to-ukraine-with-new-projects-restoring-vital-services

[29] https://commission.europa.eu/topics/eu-solidarity-ukraine/eu-assistance-ukraine/ukraine-facility_en

[30] https://www.eib.org/en/press/all/2025-180-eib-group-president-calvino-and-ukrainian-prime-minister-shmyhal-accelerate-support-to-ukraine-with-new-projects-restoring-vital-services

[31] https://www.dentons.com/en/insights/articles/2024/october/1/understanding-the-european-union-ukraine-facility

[32] https://www.eib.org/en/press/all/2024-156-eib-and-ukraine-government-sign-mou-to-accelerate-deployment-of-financial-support-and-project-execution-on-the-ground

sewerage modernisation across Ukraine, prioritising municipalities affected by the war. The project is financed by the EIB under the Ukraine Recovery Programme, in partnership with the European Union.[33] [34]

Under the Ukraine Water Recovery project, eligible municipalities can access loans aimed at (1) repairing and upgrading damaged water supply and wastewater treatment infrastructure; (2) implementing new technologies and expanding existing systems to meet current and future demands, (3) introducing energy-saving technologies to reduce operational costs and environmental impact; and (4) technical assistance during project preparation, implementation, and monitoring.[35] [36]

The project is structured as a €200 million FL, signed in February 2025, aimed at targeted investments in water supply, sewerage systems, treatment facilities, energy-efficiency upgrades, and related essential equipment. A €100 million tranche was approved under the EU-backed Ukraine Facility, and the government's cabinet authorised this EIB loan in April 2025.[37]

The Ukraine Water Recovery Project FL does not include investment grants or guarantees. Technical assistance and grants are also not provided under FL’s core financing. However, mobilisation of TA and investment grants may be facilitated by EIB under separate financing streams.[38] Despite no guarantees provided under this project, the overall financing package is backed by the EU’s Ukraine Facility guarantee, which unlocks EIB lending to higher-risk sectors and regions. **In sum, the support to municipalities under the Water Recovery Project can be arranged as a loan from EIB, typically on favourable terms, but repayable. The loan can be paired with a non-repayable grant from parallel donor programs or instruments such as EU-managed funds, UNDP, or national co-financing.**

2.2. The Ukraine Recovery Programme

Another EIB initiative, the Ukraine Recovery Programme (URP), supports the reconstruction of social infrastructure, including water systems. URP is a multi-sector framework loan of €340 million, signed in December 2020, aimed at rehabilitating critical

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[33] https://www.eib.org/en/press/all/2024-274-ukraine-eu-bank-helps-improve-water-supply-for-war-torn-bucha

[34] https://www.eib.org/en/press/all/2025-180-eib-group-president-calvino-and-ukrainian-prime-minister-shmyhal-accelerate-support-to-ukraine-with-new-projects-restoring-vital-services

[35] https://www.eib.org/fr/projects/all/20210112

[36] https://www.eib.org/en/projects/pipelines/all/20230227

[37] https://en.interfax.com.ua/news/economic/1060431.html

[38] https://www.eib.org/en/projects/all/20210112

infrastructure across Ukraine, especially in conflict-affected areas.[39] The programme operates in cycles: €14.5 million to support to municipal projects has been allocated in the framework of the latest, third, cycle.[40]

The URP builds on two previous successful cycles that have delivered to Ukraine so far more than a hundred of schools, hospitals, social housing, water plants, etc.[41] The URP prioritises investments in the recovery of areas affected by the conflict in Ukraine and basic infrastructure needs of IDPs and host communities, making it a good fit. The main instrument of the URP is repayable, concessional loans. Similarly to the Ukraine Water Recovery Project, no guarantees are provided under the URP, but the programme is backed by the EU's Ukraine Facility guarantee, unlocking EIB lending. The programme does not foresee TA, but it can be accessed through other agencies, in case it proves necessary for successful planning and implementation of the loan.[42] **Considering the municipality's previous experience of accessing EIB's loans through URP *(ibid.)*, accessing another round of funds for enhancing resilience of the selected water station maybe feasible, due to the city's familiarity with the programme and based on previous collaboration experience.**

2.3. The Ukraine Municipal Infrastructure Programme

The Ukraine Municipal Infrastructure Programme (UMIP) is a €400 million multi-sector framework loan from EIB, designed to restore and modernise municipal infrastructure across Ukraine. It supports sectors including water and wastewater, district heating, energy-efficient street lighting, waste management, and public buildings.[43] The programme is implemented jointly by Ukraine's Ministry for Communities, Territories and Infrastructure Development and the Ministry of Finance that can serve as initial entry points.[44]

EIB's loans to the Government of Ukraine are UMIP's primary instrument. These are sovereign loans, meaning the Ukrainian government borrows and then on-lends the funds to participating municipalities or utility companies for eligible infrastructure projects. Municipalities typically repay these loans, often with favorable terms.

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[39] https://www.eib.org/en/projects/all/20190903

[40] https://www.eeas.europa.eu/delegations/ukraine/ukraine-eib-provides-%E2%82%AC145-million-support-municipal-projects-war-torn-cities-mykolaiv-and-dnipro_en

[41] https://www.eib.org/en/projects/pipelines/all/20230227

[42] https://www.eib.org/en/press/all/2024-530-ukraine-eib-provides-eur55-million-to-reconstruct-social-infrastructure

[43] https://www.eeas.europa.eu/delegations/ukraine/ukraine-eib-provides-%E2%82%AC145-million-support-municipal-projects-war-torn-cities-mykolaiv-and-dnipro_en

[44] https://news.europawire.eu/eus-e3-million-injection-powers-energy-efficiency-in-ukrainian-public-buildings/eu-press-release/2023/12/29/08/32/47/127496/

To ensure successful implementation, the UMIP benefits from technical assistance funded by the Eastern Partnership Technical Assistance Trust Fund (EPTATF), managed by the EIB, and the EU Neighborhood Investment Platform (NIP).[45] The TA is provided to municipalities primarily through the Programme Management and Support Unit (PMSU). The TA may cover project preparation and feasibility studies, environmental and social impact assessments, procurement planning, and assistance with capacity-building aimed at ensuring compliance with EIB procurement rules and reporting rules, and beyond.[46] [47]

Grants are not provided under the main funding stream of UMIP but can mobilised through the EU-managed NIP or the EIB-managed EPTATF. These grants may be used to co-finance project preparation, technical assistance, and capacity-building. In some cases, capital investment grants may be blended with loans to lower the financing burden for municipalities.[48]

In sum, the blended financing model of a loan and TA funded under UMIP, complemented by a grant from either NIP or EPTATF, can be a feasible solution for financing the installation of a renewable/solar park at the selected water station. The entire public investment management cycle — from project initiation and preparation of design and estimate documentation, to the allocation of funding and its implementation — is managed through the **DREAM platform**. The platform also automatically shares information about the availability of new funding sources.

2.4. Technical assistance under JASPERS

JASPERS (Joint Assistance to Support Projects in European Regions) is a high-level advisory and technical assistance programme launched by the European Commission, the EIB and the EBRD in 2005 to support EU regions and, since 2022, Ukraine and Moldova. Its purpose is to enhance quality, readiness, and EU-alignment of investment projects, especially in sectors like transport, energy, water, waste, housing, public infrastructure, and mobility. EIB is the programme's lead administrator and manages its daily operations, coordination, and advisory delivery; while the European Commission and EBRD perform governance and oversight.

[45] https://www.eib.org/en/press/all/2025-001-ukraine-eib-provides-eur4-7-million-for-waste-management-improvements-at-lviv-s-hrybovychi-landfill

[46] https://www.eib.org/en/press/all/2023-402-eib-continues-support-to-mykolayiv-water-and-wastewater-modernisation

[47] https://www.egis-group.com/projects/umip-ukraine

[48] https://www.eib.org/en/press/all/2023-402-eib-continues-support-to-mykolayiv-water-and-wastewater-modernisation

Municipal or regional authorities can access free-of-charge advisory services at any stage — from project idea to implementation. JASPERS experts help review project concepts, refine technical designs, enhance economic viability, and align documentation with EU funding standards. Local authorities can also receive training and tools to boost their public investment management capacity, implementation capacity, and strategic planning skills. The focus areas include procurement, environmental compliance, project evaluation, and technical advisory alignment with EU norms.[49]

A €20 million advisory support package (€10m from the Commission and €10m from the EIB) provides institutional strengthening under JASPERS in Ukraine, running through to 2028. As part of the "EU4U" on-site consultancy programme, JASPERS has engaged local experts to provide day-to-day advisory assistance to national ministries and municipalities.[50] Engaging with TA and/or capacity-building under JASPERS can aid implementation of the installation of the renewable energy technology at the water station, support the municipality in project management, and positively contribute to the municipality's actual and perceived implementation capacity, favouring investments from IFIs.

2.5. Typical loan amounts provided by EIB

Typical loan amounts for municipal water recovery under EIB programmes are in the range of €4–20 million, with €20 million being standard for a complete city water infrastructure project. Depending on scope and context, smaller-scale repairs or targeted interventions may also be financed. For example, in 2023, EIB approved a €20M loan for Mykolaiv to modernise its water treatment plant, pumping stations, and wastewater facilities. This framework loan (under the Ukraine Water Recover) covers multiple municipal-level subprojects, allowing funding allocation city-by-city over time.[51] This is a typical example of a medium-sized loan supporting a municipal water project.

In addition to large and mid-size loans, the EIB is also known to have financed small-scale water rehabilitation projects, such as a €100,000 water rehabilitation project in Bucha aimed at upgrading its de-ironing water station under the Ukraine Recovery Programme umbrella.[52] **This illustrates that local projects can vary widely in size, from under €1M for targeted repairs to much larger rehabilitation schemes.**

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[49] https://eu-mayors.ec.europa.eu/en/node/66

[50] https://www.eib.org/en/press/news/ukraine-wins-eur20-million-eu-extension-of-advisory-assistance-for-economic-development

[51] https://eu4ukraine.eu/en/whats-happening-en/news-en/20-million-loan-for-mykolayiv-water-and-wastewater-improvement-en.html

[52] https://www.eib.org/en/press/all/2024-274-ukraine-eu-bank-helps-improve-water-supply-for-war-torn-bucha

Framework loans (e.g., Ukraine Water Recovery) enable broad multi-location support. Individual municipal sub-projects often fall for major infrastructure rehab in the €10M–€20M range. Smaller municipal upgrades or pilot facilities can be funded at a scale starting from €100K. These financing scales allow the EIB to tailor support — from broad infrastructure overhauls in large cities to targeted interventions in smaller or newly liberated communities.

It is crucial to discuss the potential for financing the mid- to small-scale intervention of €2.5 - 3.5 million. Alternatively, combining repairs and enhancing the resilience of several infrastructural facilities can be considered to qualify for [typically larger] funding from institutions like EIB and EBRD.

3. The Nordic Environment Finance Corporation (NEFCO)

NEFCO is an international financial institution that focuses on financing green growth investments in Eastern Europe, with a strong emphasis on energy efficiency and renewable energy projects for both private and public sectors. NEFCO has a significant track record of working with municipal projects in Ukraine, particularly in the energy and water sectors.[53] NEFCO supports Ukraine's reconstruction and resilience foremost through its Green Recovery Programme for Ukraine that is currently entering second phase. Namely, the 41-month programme commences in August 2025, and its overall budget is expected to reach €6 million. **The proposed typical project size is in the range of €1-15 million depending on identified needs and potential of energy efficiency improvements[54], matching the needs of the selected object.** The programme sees Ukrainian municipalities as key actors of reconstruction and specifically targets infrastructure repair and the green transition, showing a great cooperation potential.[55]

NEFCO provides loans, grants (often in partnership with the EU, E5P, or Nordic countries' governments), and technical assistance to support project preparation, feasibility studies, procurement and implementation support, environmental assessments and beyond. The Green Recovery Programme for Ukraine provides financial support and TA to municipalities in Ukraine to address both direct and indirect consequences of the war. One of the program's priorities is renovating and building

[53] https://www.eif.org/InvestEU/news/2025/nordic-businesses-to-get-green-financing-boost-as-eif-teams-up-with-regional-lender-nefco.htm

[54] https://www.nefco.int/wp-content/uploads/2025/06/rfp-technical-support-under-ngrpu-stage-2.pdf

[55] https://www.nefco.int/procurements/request-for-proposals-technical-assistance-nefco-green-recovery-programme-for-ukraine-second-phase/

utilities and facilities serving IDPs[56], showing an even greater potential for collaboration and financing for the municipal enterprise in the city that is a host community for numerous IDPs.

Moreover, the Green Recovery Programme is known to have financed critical infrastructure (district heating and water & wastewater) repairs in 12 communities in Kyiv region, as well as water system modernisation in six communities across Ukraine. In total, NEFCO has financed have financed more than 300 public sector projects in Ukraine, attracting over €323 million, to support the country in its green transition.[57] **NEFCO's specific focus on green recovery and its experience with similar municipal projects make it a highly relevant institution.**

4. Co-financing grants under E5P

One of the funds that could potentially provide co-financing for the project in focus is the Eastern Europe Energy Efficiency and Environment Partnership — E5P. The fund is a multi-donor initiative, with the EU as the largest donor, that provides grant co-financing for energy efficiency and environmental projects in Eastern Partnership countries, particularly Ukraine. It is designed to support municipal infrastructure projects that are co-financed by international financial institutions like the EBRD, EIB, and NEFCO.[58]

While the E5P has a notably smaller budget than a typical development bank-financed loan, it can be a useful instrument to finance the project by utilizing a blended finance structure — a loan from an IFI paired with a grant from the E5P. The blended financing structure, where a part of the cost is covered with a non-repayable grant, is likely to be more feasible, ensuring improved project viability, risk sharing, and alignment with green/climate objectives.

E5P supports municipal enterprises in Ukraine to install renewable energy technologies through non-repayable *Capital Grants* and *Blended Finance* paired with loan financing from development banks, to offset project costs and address high upfront capital

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[56] https://www.nefco.int/financing/municipalities-in-eastern-europe/green-recovery-ukraine/

[57] https://www.nefco.int/financing/municipalities-in-eastern-europe/previous-activities-in-ukraine/

[58] https://e5p.eu/ukraine

needs.[59] E5P is known to have funded building a solar power plant at Chortkiv's water utility (Ternopil region) in the amount of €460,000.[60]

5. World Bank Group

The World Bank Group is a key actor and decision-maker for multiple financing mechanisms that have a high potential relevance. The Word Bank's approach is guided by the Rapid Damage and Needs Assessment (RDNA4) and addresses both the immediate humanitarian and economic challenges and the long-term requirements for sustainable rebuilding. RDNA4 highlights the extensive destruction of Ukraine's energy infrastructure, underscoring the urgent need for recovery and the implementation of resilient energy solutions.[61]

5.1. The Ukraine Relief, Recovery, Reconstruction and Reform Trust Fund (URTF)

A key mechanism for the World Bank's financial assistance is the Ukraine Relief, Recovery, Reconstruction and Reform Trust Fund (URTF). This multi-donor fund provides grants and TA to address Ukraine's most pressing needs, including repairing damaged infrastructure and restoring essential energy services. **Given the critical nature of the station's water supply services and the vulnerability of its energy infrastructure, exploring potential funding through the URTF is a viable step.** Grant funding through the URTF is generally channelled through national government programs, meaning that the eligibility of the water station project would likely depend on its alignment with national priorities and the specific criteria of relevant government initiatives. The URTF's focus on immediate recovery and resilience-related needs and its ability to mobilise resources quickly make it an appropriate option for the proposed renewable/solar energy installation. Similarly to the UMIP, the URTF projects full cycle is also managed via the DREAM platform. Grants under URTF are compatible with other financing mechanisms supporting Ukraine's reconstruction and energy resilience, including EBRD and EIB loans.[62]

5.2. IFC's Economic Resilience Action Program for Ukraine

[59] https://www.ebrd.com/home/news-and-events/news/2024/supporting-ukraine-with-517-million-of-eu-funding-through-ebrd.html

[60] https://www.nefco.int/news/nefco-and-e5p-sign-grant-agreements-to-advance-the-green-transition-in-chortkiv-and-boost-energy-efficiency-in-vinnytsia/

[61] https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099022025114040022

[62] https://www.worldbank.org/en/programs/urtf

In 2025-2027, another World Bank Group's member, the International Finance Corporation (IFC) will deploy $2 billion to support Ukraine's economy, infrastructure, and provision of essential services, especially for IDPs and host communities. Since the beginning of the full-scale invasion and until July 2025 [when this report is drafted], the IFC has committed $2.4 billion in financing, including $908 million mobilised from partners and donors.[63]

The IFC supports Ukraine through its Economic Resilience Action (ERA) Program. The ERA programme focuses on (1) sustaining economic activity and supplying essential goods; (2) supporting vital economic infrastructure; and (3) addressing the needs of displaced people and affected municipalities.[64]

ERA's core feature is credit enhancement via loan guarantees to attract private investment. The IFC is also known for successfully leveraging backing from private sector partners to maximise capital mobilisation for the reconstruction, from which the project in focus may benefit.[65] **The ERA programme prioritises enabling investment in improving municipal infrastructure's resilience and energy security, prioritising IDPs and host communities, making it a viable potential partner.**

5.3. PREPARE Ukraine Program

In July 2025, the Government of Ukraine signed an agreement with the International Bank for Reconstruction and Development (IBRD) and the International Development Association (IDA) to launch a five-year, $200 million PREPARE Ukraine program. The initiative is designed to finance the preparation of state and municipal reconstruction projects so that meet requirements of international investors and can be implemented quickly. The Public-Private Partnership Agency will manage the programmeunder the coordination of the Ministry of Economy, Environment, and Agriculture of Ukraine.

An initial grant of $44.3 million from the URTF will be used to build a public investment portfolio and strengthen institutional capacity. **The first tranche will be available for use starting in August 2025 and will cover technical support for government clients, including municipalities.** The program's operational manual is yet to be approved by the World Bank and the Ministry of Economy, Environment, and Agriculture of Ukraine.[66]

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[63] https://www.ifc.org/en/where-we-work/country/ukraine

[64] https://www.ifc.org/content/dam/ifc/doc/2023/ifc-economic-resilience-action-program-for-ukraine.pdf

[65] https://www.ifc.org/content/dam/ifc/doc/2023/ifc-economic-resilience-action-program-for-ukraine.pdf

[66] https://ukraineinvest.gov.ua/en/news/ukraine-and-the-world-bank-agree-to-launch-prepare-ukraine-program-to-develop-reconstruction-projects/

Seeing that PREPARE Ukraine is commencing as this report is being drafted, it could be timely for the municipality to engage with the programme early, to build trusted partnership and receive timely updates about opportunities potentially emerging within the programme in the near future.

5.4 The Multilateral Investment Guarantee Agency (MIGA)

The Multilateral Investment Guarantee Agency (MIGA) also plays a crucial role in financing Ukraine's energy resilience by providing guarantees to investors and lenders, encouraging foreign direct investments and helping to mitigate associated risks. While MIGA does not directly finance projects, its guarantees can be instrumental in attracting private sector investment, particularly in a challenging environment like Ukraine. MIGA has been among few providers of political risk insurance in Ukraine, including cover for war and civil disturbance, issuing more than $215 million in coverage since the Russian invasion of Ukraine in February 2022.[67]

MIGA uses the Support for Ukraine's Reconstruction and Economy Trust Fund (SURE TF) to enable its guarantee issuance in Ukraine.[68] The SURE TF was established to help MIGA deploy a two-fold strategy in Ukraine: (1) to enable private investment by providing guarantees (political risk insurance and credit enhancement) to investors and lenders, and (2) to ensure that projects are implemented in accordance with global best practices on meeting integrity, environmental, social, and climate standards. Amidst limited availability of private reinsurance, SURE TF enables MIGA's guarantee issuance in Ukraine by sharing up to 75% of the risk.[69] **MIGA and its SURE TF could be relevant, in the case the municipality decides to pursue a public-private partnership model for financing its renewable energy project.**

Conclusions and next steps

Modelling results

In conclusion, this study evaluated multiple renewable energy and heating configurations to identify the site's most technically viable, economically competitive, and operationally reliable solutions. Both hybrid energy configurations, PV + battery and wind + battery, display strong technical viability and economic competition. The PV

[67] https://www.miga.org/press-release/miga-expands-insurance-support-ukraine

[68] https://www.miga.org/support-ukraines-reconstruction-and-economy-trust-fund-sure-tf

[69] https://thedocs.worldbank.org/en/doc/343066070fa8afd1b950c650fdeb9c7c-0080012025/original/WBG-Support-Ukraine.pdf

system offers a high annual generation of 62.78 GWh with a lower LCOE of € 0.0741/kWh, while the wind system, although slightly less productive at 58.5 GWh, with a LCOE of € 0.0244/kWh, receives significantly less LCOE. However, due to the high capital and replacement costs, the overall system LCOE, including storage and conversion for PV, is € 0.412/kWh. Both systems produce significant excess electricity for PV of 40.5 GWh and 37.4 GWh for air, which remain unused due to legal restrictions restricting grid exports. It underlines technical oversupply, regulatory obstacles, large storage capacity, dynamic load integration, or the need for policy reforms to unlock the full value of the renewable generation.

Both viable solutions, solar PV + grid and solar PV + battery + grid, provide reliable hybrid energy options with the penetration of ~ 9–9.4%. The PV + Grid configuration receives an LCOE of € 0.113/kWh, relies on grid imports for more than 90% energy needs, while 374 MWh/year produces additional power that can be exported or managed. The PV + Battery + Grid Setup introduces limited storage of 4.2 MWh, which marginally reduces the reliance, but still covers only ~ 9.3% of the annual load through the PV generation and yields LCOE of € 0.114/kWh. Additional power is maintained due to technical barriers (limited storage) and legal obstacles (restrictions on grid exports). This highlights the need for policy support, extended storage capacity, and demand management to benefit the renewable generation fully while maintaining cost-effectiveness and system reliability.

Technical-economic analysis of heating technologies for the selected water supply station identifies WWHP as an optimal solution to achieve an efficient, low-carbon heating solution. From a technical point of view, WWHP requires at least an electrical input of 556,289 kWh annually to complete a fixed thermal load of WWHP 3,059,588 kWh. Its required heating capacity of 127 kW ensures reliable operation with minimal impact on the power infrastructure of the station. WWHP displays better energy efficiency, low operational sensitivity for ambient temperature, and compatibility with existing hydronic systems compared to AWHP and AAHP. From an economic perspective, the lowest total annual cost is € 290,011 due to significantly reduced variable energy expenses, despite a higher upfront investment. When integrating solar PV to offset power consumption, WWHP remains the most cost-effective solution with the lowest joint cost of € 850,936 compared to other heat pump types, requiring a small and less expensive solar installation. Considering the deficiency of the site, such as a limited available area of 8,712 m^2 and especially the inability to allocate additional PV capacity for heating, the compact footprint of WWHP makes it the sole viable and scalable solution. Although 100% on-site solar coverage is not obtainable, partial PV integration will jointly increase energy autonomy with grid or off-site renewable energy. Overall, a WWHP system provides the best balance of energy efficiency, operational reliability, and long-term cost-effectiveness. **In sum, the total investment in both the electric and heating systems depends on the feasibility choices made by the water facility station.**

Financing opportunities

The EBRD's strategic emphasis on enhancing energy security and facilitating the green transition makes it a good potential partner to finance installation of renewable energy technology at the water supply station. **EBRD supports Ukraine and specifically Ukrainian municipalities through several programmes, including ESSF, the Hi-Bar Programme, and UIF MIIR. While ESSF and the Hi-Bar programme primarily provide guarantees than enable IFI's and national banks to provide loans, as well as technical assistance for project development and implementation, UIF MIIR also provides grants that can enhance financial viability of the project.** Seeing EBRD's strong focus on supporting Ukraine's energy resilience and the green transition, as well as its key role in a number of financial programmes and mechanisms for Ukraine, building a partnership with the Bank and exploring collaboration opportunities thoroughly is a vital step. **For the most efficient communication, the report recommends filling in EBRD's financing request form prior to contacting their office in Kyiv** (see Annex III for the list of contacts).

The EIB also has demonstrated a strong and consistent commitment to supporting Ukraine's resilience, economic stability, and recovery efforts, particularly focusing on the energy and infrastructure sectors. Many of EIB's financing packages are channelled through the European Union's Ukraine Facility, often including specific programs and initiatives that target critical infrastructure needs. EIB's support to Ukrainian municipalities is primarily channelled through loans and guarantees, in some cases supported by mobilisation of grants and technical assistance. **Under the Ukraine Water Recovery Framework Loan administered by EIB, the municipality can potentially access a loan to install renewable energy technologies at the water supply station**, as it matches the project's priorities.

Another EIB's initiative, the Ukraine Recovery Programme, prioritises the reconstruction of social infrastructure, including water systems, specifically focusing on regions hosting IDPs, making it a significant potential collaborator. **The main instrument of the URP is concessional loans, backed by the EU's Ukraine Facility guarantee, that can also be combined with grants and TA from other IFIs.**

The Ukraine Municipal Infrastructure Programme, administered by EIB and co-implemented by Ukraine's Ministry for Communities, Territories and Infrastructure Development and the Ministry of Finance, offers a blended financing model of a loan and TA that also can be complemented by a grant from another institution. **The UMIP is managed through the DREAM platform and may be an attractive partnership for the municipality, due its blended financing model** and to being implemented by the Ukrainian Ministries, potentially easing communication and favouring collaboration.

The high-level technical assistance programme JASPERS co-managed by the European Commission, the EIB and the EBRD provides an opportunity to municipal and regional authorities to access free-of-charge advisory services at any stage of the project — from project idea to implementation. JASPERS experts can review project concepts, refine technical designs, enhance economic viability, and align documentation with EU funding standards. The programme also offers capacity-building support to aid implementation, monitoring, and reporting. Given that the project idea and design have already been initiated under this report, TA from JASPERS could be especially beneficial, due to its flexibility and access to intelligence of some of the most significant institutions in the field of financing renewable energy technologies for infrastructural projects in Ukraine.

This report also recommends to consider opportunities for financing the installation of renewable energy technologies at the selected water station through NEFCO, especially as the institution has a significant track record of working with municipal projects in Ukraine. **NEFCO provides loans, grants (often in partnership with other organisations), and TA for project preparation, feasibility studies, procurement and beyond. A typical project financed by NEFCO ranges between €1-15 million**, making this potential partnership particularly relevant, due to the appropriate financing amount.

To complement loans under the EBRD, EIB, NEFCO, or another IFI, **grants by E5P** should be considered. In case of small- to mid-size loans to borrowers that may be considered higher-risk by some lenders, blended financing that pairs loans and grants can help to offset project costs, address high upfront capital needs, and de-risk loans. Therefore, a E5P grant may be instrumental for financing the installation of renewable energy technologies at the water supply station.

Another key actor and decision-maker for multiple financing mechanisms that have a high potential relevance is **the World Bank Group**. Guided by the RDNA4, one of its key mechanisms — **the URTF — provides grants and TA to address Ukraine's most pressing needs, including restoring essential services.** Another World Bank Group's member, the IFC, plans to deploy $2 billion to support Ukraine's economy, infrastructure, and provision of essential services in 2025-2027. **The IFC operates through its ERA programme that prioritises IDPs and host communities,** making it a viable potential partner. **The SURE Trust Fund that operates under the Multilateral Investment Guarantee Agency could be a feasible partner,** i**n the case the municipality decides to pursue a public-private partnership model for financing its renewable energy project.** Finally, the $200 million **PREPARE Ukraine programme** that is designed to finance the preparation of state and municipal reconstruction projects (TA) is commencing as this report is being drafted, making it a significant opportunity for the municipality, in case TA needs are identified.

In sum, while this report recommends exploring and considering all financing opportunities listed above, it suggest prioritising opportunities that fit the blended financing model that allows to combine loans, grants, and TA, supported by guarantees as necessary. The following financing opportunities are the most feasible for financing the installation of renewable energy technologies at the water station:

1. A loan under the Ukraine Water Recovery FL (administered by EIB);
2. A loan under the Ukraine Municipal Infrastructure Programme administered by EIB and implemented by Ukraine's Ministry for Communities, Territories and Infrastructure Development and the Ministry of Finance;
3. TA under JASPERS to obtain intelligence and guidance from key potential financing institutions: the EIB, the EBRD, and the European Commission;
4. A loan and/or grant under NEFCO;
5. Co-financing grant from E5P to de-risk a potential loan.

Annex I – Cost data used for Modelling

Technology	Capital cost €	O&M cost €	Source	Lifetime
Solar PV – 1 kW	1200	10	NECP UA	25
Onshore wind turbine – 2 MW	2.6 million	26000	HOMER Pro	20
Converter	300	0	HOMER Pro	15
Battery Li-ion 1MW	500000	5000	HOMER Pro	15

System	CAPEX [70](Euro/kW)	OPEX [71](Euro/kW)	Variable cost [72](Euro/kWh)
Water-to-Water HP	1633	32.66	0.14
Air-to-Water HP	1313	26.26	0.14
Air to Air Heat pump	1057	21.14	0.14

Annex II – Financing sources

Implementing Institution	Programme / project	Grants	Loans	Guarantees	Technical Assistance
EBRD	Energy Security Support Facility (ESSF)	In some cases (post-investment grants only)	No, but enables local banks to provide loans through guarantees	Yes	Yes
EBRD	Hi-Bar Programme	No	No	Yes	Yes
EBRD	Municipal, Infrastructure & Industrial	Yes	No	Yes	Yes

[70] https://www.futureheat.info/post/irena-report-presents-update-on-heat-pump-costs-and-markets; pg 43

[71] Assumed 2.5% of the CAPEX is OPEX

[72] https://www.globalpetrolprices.com/Ukraine/electricity_prices/

	Resilience guarantee (UIF MIIR)				
Eastern Europe Energy Efficiency and Environment Partnership — E5P	—	Yes, but only blended with loans by IFIs	No	No	No
The European Investment Bank (EIB)	Ukraine Water Recovery	No / Indirect role: The project mobilises grant opportunities, but does not provide grants	Yes	No	Indirect role: The project mobilises TA opportunities, but does not directly provide TA
The European Investment Bank (EIB)	Ukraine District Heating	No	Yes	No	No
The European Investment Bank (EIB)	Ukraine recovery and Infrastructure Programme	No, but in some cases there is a possibility to mobilise loan-compatible NIP or EPTATF grants	Yes	No	Indirectly, through NIP and EPTATF
The European Investment Bank (EIB)	Guarantees under the EU's Ukraine Facility	No	No	Yes	No
The Nordic Environment Finance Corporation (NEFCO)	Green recovery Programme for Ukraine	Yes	Yes	Yes	No
The World Bank Group (WB)	The Ukraine Relief, Recovery, Reconstruction and Reform	Yes	No	No	Yes

	Trust Fund (URTF)				
The International Finance Corporation (IFC)	The Economic Resilience Action Program for Ukraine (ERA)	No	No	Yes	No
The International Bank for Reconstruction and Development (IBRD) and the International Development Association (IDA)	PREPARE Ukraine	Yes, but only for technical project preparation, institutional capacity-building, and establishing pipelines of high-quality, bankable project	No	No	Yes
The World Bank Group (WB)	The Multilateral Investment Guarantee Agency (MIGA)	No	No	Yes	No

Annex III – Contacts of IFIs

Institution	Programme	Represenative's name	Name	Email	Phone
EBRD	-	Managing Director, Head of Ukraine and Moldova	Arvid Tuerkner	kyiv@ebrd.com	380442771160
	Energy Security Support Facility	-	-	info@essf-ukraine.com	380967681353
	Hi-Bar Programme	-	-	fundingdesk@ebrd.com	
EBRD's financing request form	https://www.ebrd.com/home/forms/business-enquiry.html				
EIB	-	Head of Office in Kyiv	Kristina Mikulova	k.mikulova@eib.org	380443908018

JASPERS contact form	https://jaspers.eib.org/get-in-touch/index.htm				
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World Bank	Ukraine Country Office	-	-	ukraine@worldbank.org	380444906671
	-	World Bank Regional Country Director for Eastern Europe	Bob Saum	bsaum@worldbank.org	-
	Multilateral Investment Guarantee Agency	Head of Eastern Europe and Central Asia	Olga Sclovscaia	osclovscaia@worldbank.org	-

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