# TECHNICAL AND ECONOMIC SCREENING FOR POTENTIAL OF DISTRIBUTED ENERGY RESOURCE INTEGRATION AT CHERVONOHRAD WATER UTILITY IN UKRAINE

Dan Olis and Anastasiia Sakharova

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# List of Acronyms

| | |
|---|---|
| BESS | battery energy storage system |
| DER | distributed energy resource |
| NREL | National Renewable Energy Laboratory |
| PV | photovoltaics |

# Executive Summary

In this report, we present a preliminary techno-economic screening for distributed renewable energy for Chervonohrad Vodokanal, the water utility in Chervonohrad, Ukraine. The screening estimates the technical potential and economics of integrating solar photovoltaics (PV) and battery energy storage systems (BESS) at Chervonohrad Vodokanal water pumping stations, Pravda, Bendiuha, and Mezhyrichchya.

The pumping stations currently source electricity from the local power utility. Each station also currently has backup power generators to provide power to critical loads during periods of utility power loss.

This analysis finds that solar PV is a cost-effective supplemental power source for the pumping stations. The addition of PV will reduce electric utility costs and, during grid outages, has the potential to extend stored fuel to enable the backup systems to serve critical loads for longer durations.

The integration of battery energy storage is not found to be cost-effective at the three pumping stations. The solutions for each site are summarized in Table ES- 1.

At the Bendiuha station the cost-optimal PV system is constrained by the available land area, estimated to be approximately 28 kW-DC. This system would provide about 6% of annual energy, resulting in $4,900 in energy bill savings and a simple payback of 4.9 years, considering a $0.20/kWh electricity tariff. Sites Mezhyrichchya and Pravda are not space-constrained.

At Mezhyrichchya, a 79-kW-DC PV system is found to be cost-effective. This system is estimated to provide approximately 22% of annual energy and reduce annual utility electricity costs by approximately $11,500.

The Pravda pumping station can cost-effectively host 73 kW-DC of solar PV to provide about $10,500 in annual electricity bill savings and 21% of annual energy. The estimated simple payback periods for Mezhyrichchya and Pravda are both 6.0 years.

**Table ES- 1. DER Solution for Each Pumping Station**

| Facility | Bendiuga | Mezhyrichchya | Pravda |
|---|---|---|---|
| PV Capacity (kW-DC) | 28 | 79 | 73 |
| Annual PV Generation (MWh) | 24.7 | 69.9 | 64.0 |
| BESS (kW) | 0 | 0 | 0 |
| PV Used (MWh) | 24.7 | 57.6 | 52.3 |
| PV Exported (MWh) | 0.0 | 12.3 | 11.7 |
| PV Exported (%) | 0% | 18% | 18% |
| Renewable Fraction | 6% | 22% | 21% |
| Utility Bill Savings, Year 1 ($) | $4,900 | $11,500 | $10,500 |
| Net Present Value ($) | $51,400 | $104,500 | $94,200 |
| Capital Expenditure ($) | $23,800 | $67,400 | $61,700 |
| Simple Payback (years) | 4.9 | 6.0 | 6.0 |

Cost-effective capacities and financial metrics presented in this report are estimates based on the data and assumptions available at the time of writing. Actual project financial metrics are dependent on actual system costs and future costs of utility electricity.

Information to inform cost assumptions was provided by in-country developers and non-profits working in the renewable energy sector. The cost assumptions used are general estimates for distributed energy resources and do not consider site-specific details nor the market in Chernovnohrad.

It is recommended that Chervonohrad Vodokanal's next steps are to seek in-country experts to review the locations identified for PV installation and each facility's electrical system to refine costs and technical potential. Integrating PV for utilization during grid outages requires examining its potential impact on ramping and loading of the backup reciprocating engine generators. Without proper design to ensure stable operation of the backup system, critical water service could be jeopardized. A review of the backup power system and whether it may be feasible to integrate solar PV without negatively impacting the generator can be completed as a follow-up to this report. This report and the site assessment report can be used to seek funding partners or release a request for proposals from qualified developers.

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# 1 Introduction

The National Renewable Energy Laboratory (NREL) is providing technical assistance to Ukraine under programs funded by the U.S. Agency for International Development Mission to Ukraine and the U.S. Department of Energy's Net Zero World initiative.

Two of the stated national goals for the government of Ukraine are to increase the level of distributed energy resources (DERs) and increase the resilience of Ukraine's power system. The Ukraine Facility Plan states that the strategic goals include "supporting a green transition in the energy sector and promoting an increase in the share of renewable energy, which will also serve to strengthen the decentralisation of the energy system and simultaneously increase energy security" (Ukraine Facility 2024). Additionally, the Annex to the Action Plan for the implementation of the Energy Strategy of Ukraine until 2050 lists an inclusion of mechanisms to encourage the implementation of DERs among the planned initiatives (Ministry of Energy of Ukraine 2024).

This report describes the results of an analysis for DERs at three water pumping stations in Chervonohrad, Ukraine. The pumping stations provide domestic water to customers of the Chervonohrad Vodokanal water utility. The DERs considered are solar photovoltaics (PV) and battery energy storage systems (BESS). We estimated the technical and economic potentials for these DERs using NREL's System Advisor Model (SAM) and REopt® model. REopt is a mixed-integer model that determines the cost-optimal deployment of distributed energy technologies while adhering to operational constraints (Cutler, et al., 2017). The REopt optimization identifies the system sizes and dispatch strategies that minimize the lifecycle cost of energy for a particular site. SAM is a technoeconomic model that calculates performance and financial metrics of renewable energy and storage systems. Resources for these software tools, including descriptions of methodologies, can be found here:

- System Advisor Model, https://sam.nrel.gov/, and
- REopt, https://www.nrel.gov/reopt/

# 2 Water Pumping Station Sites

NREL assessed the three water pumping stations in Chervonohrad, Ukraine, for the addition of solar PV and battery energy storage. The three sites are Bendiuha, Mezhyrichchya, and Pravda. Each station has pumps for distributing potable water. The monthly electricity consumption, typical daily power demand, and retail electricity costs were provided by Chervonohrad Vodokanal water utility staff for this analysis. In addition, the ground area available for solar PV was estimated by water utility staff.

## 2.1 Electricity Consumption and Costs

Table 1 summarizes the power demand and energy consumption for each location and the estimated ground area for supporting PV. Annual estimated electricity costs are also included based on the current rate tariff of 7.64 Ukrainian hryvnia (UAH) per kWh, or $0.20/kWh USD.[1]

**Table 1. Electricity Consumption and Costs**

| Facility | Bendiuha | Mezhyrichchya | Pravda |
|---|---|---|---|
| Average Load (kW) | 48.6 | 32.6 | 27.1 |
| Annual Load (MWh) | 426 | 286 | 237 |
| Peak Load (kW) | 65 | 33 | 29 |
| Available Area for PV ($m^2$) | 450 | 2,000 | 5,200 |
| Maximum PV Hosting Capacity (kW-DC) | 28 | 127 | 330 |
| Existing Backup Generator | Yes | Yes | Yes |
| Annual Electric Utility Cost (USD) | $85,200 | $57,200 | $47,400 |

The rate tariff for the pumping stations does not include any differences in pricing by time of use, weekend or weekday, or seasons. There are also no costs levied on peak average demand (kW) over some time interval (e.g., 15-minute period). The tariff is simply a flat energy charge for all consumption. We used a flat $0.20/kWh USD tariff for techno-economic analysis in this report.

The 2023 monthly energy consumption for the pumping stations is shown in Figure 1.

[1] Using currency conversion of 38 UAH per USD from the *Wall Street Journal* (https://www.wsj.com/market-data/quotes/fx/USDUAH/historical-prices).

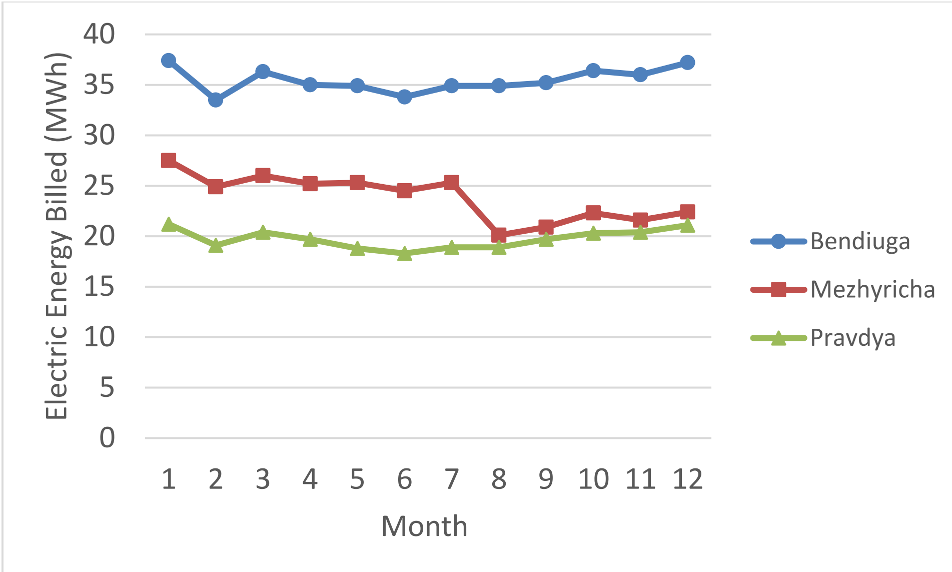


**Figure 1. Monthly energy consumption for Bendiuha, Mezhyrichchya, and Pravda pumping stations**

Figure 2 shows the daily demand profiles as provided in sketches by water utility staff. Actual interval data from a power meter is unavailable.

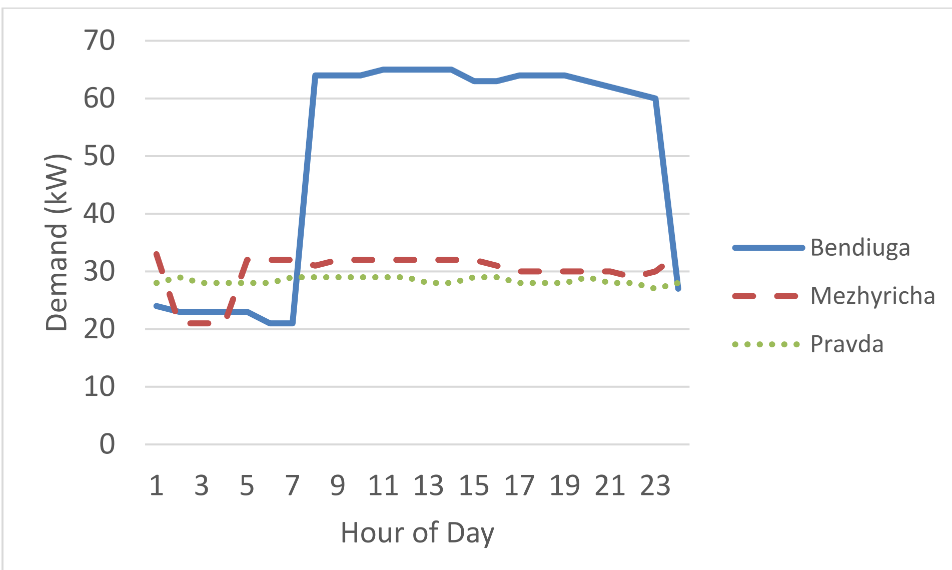


**Figure 2. Approximate typical daily load profiles**

## 2.2 Available Space for PV

The ground area available to support the installation of solar PV was provided by the staff of the water utility. The ground area and PV hosting capacity of each area is shown in Table 2. The hosting capacity estimate is based on values from NREL's System Advisor Model, using a module footprint of 4.72 square meters per kW-DC and a default ground coverage ratio of 0.3.

**Table 2. Available Area and Estimated Area PV Hosting Capacity**

| Facility | Bendiuha | Mezhyrichchya | Pravda |
|---|---|---|---|
| Available Area for PV ($m^2$) | 450 | 2,000 | 5,200 |
| Maximum PV Hosting Capacity (kW-DC) | 28 | 127 | 330 |

Due to the continued Russian war against Ukraine and the declaration of martial law there, the precise locations of the pumping stations were not provided to NREL. As a result, NREL staff were unable to provide a desktop review of satellite imagery. These results therefore assume the sites are relatively flat and free of shading from structures and vegetation.

# 3 Technical and Economic Potential of PV and BESS

## 3.1 Analysis Results

This analysis finds that solar PV is a cost-effective supplemental power source for the Bendiuha, Mezhyrichchya, and Pravda pumping stations and that BESS is not cost-effective at any of the three locations.

Key metrics of the techno-economic analyses, including DER capacities, capital costs, Year-1 bill savings, net present value, and simple payback are shown for each location in Table 3. The net present value is based on a 25-year analysis period.

**Table 3. Most Cost-Effective PV and BESS Solution for Each Pumping Station**

| Facility | Bendiuha | Mezhyrichchya | Pravda |
|---|---|---|---|
| PV Capacity (kW-DC) | 28 | 79 | 73 |
| Annual PV Generation (MWh) | 24.7 | 69.9 | 64.0 |
| BESS (kW) | 0 | 0 | 0 |
| BESS (kWh) | 0 | 0 | 0 |
| PV Energy Consumed (MWh) | 24.7 | 57.6 | 52.3 |
| PV Energy Exported (MWh) | 0.0 | 12.3 | 11.7 |
| PV Energy Exported (%) | 0% | 18% | 18% |
| Renewable Fraction | 6% | 22% | 21% |
| Utility Bill Savings, Year 1 ($) | $4,900 | $11,500 | $10,500 |
| Capital Expenditure ($) | $23,800 | $67,400 | $61,700 |
| Net Present Value ($) | $51,400 | $104,500 | $94,200 |
| Simple Payback (years) | 4.9 | 6.0 | 6.0 |

Cost-effective capacities and financial metrics presented in this report are estimates based on the data and assumptions available at the time of writing. Actual project financial metrics are dependent on actual system costs and future costs of utility electricity. However, the economics for PV are strong, given the current high electricity costs; positive net present values are expected even if PV system cost estimates used in this analysis are lower than actual bid estimates. The projects could potentially become uneconomic if costly upgrades to the electrical system are needed to enable PV integration at the sites. For each location, the capital costs could increase up to the net present value shown in Table 3 before the projects fail from an economic cost perspective.

The Bendiuha station is constrained by available land area, and the PV system there is sized to this constraint, 28 kW-DC. If additional ground or rooftop space were available, a larger system would be more cost-optimal. This system is estimated to provide about 6% of annual energy, results in $4,900 in bill savings, and has a simple payback of 4.9 years.

Sites Mezhyrichchya and Pravda are not space-constrained. At Mezhyrichchya, a 79-kW-DC PV system is found to be cost-effective, which can provide approximately 22% of annual energy and reduce annual utility electricity costs by approximately $11,500. The Pravda pumping station can cost-effectively host 73 kW-DC of solar PV to provide about $10,500 in annual bill savings and 21% of annual energy. The estimated simple payback periods for Mezhyrichchya and Pravda are both 6.0 years.

During normal operations, the PV system would operate in parallel with the utility, providing all, some, or no power to the pumping station, depending on the amount of solar power generated at any moment.

Including BESS at both Mezhyrichchya and Pravda could allow a larger installation of solar PV at each location to enable a greater share of power needs to be provided by PV. But adding BESS for this purpose is not cost-effective. Additionally, BESS are often utilized to shift utility consumption from periods when electricity cost is relatively high to periods when electricity cost is lower. BESS are also effective for reducing power demand if a component of the electricity bill includes peak demand charges. The electricity rate tariff for the water utility does not include time-of-use energy charges (electricity costs that vary by time of day) nor demand charges. Without these tariff features, two key economic drivers for utility bill savings with BESS are not present. BESS coupled with PV can also be used to provide backup power during a loss of grid power. However, because each of the pumping stations has existing, functional backup power generators, it is not cost effective to add BESS at these locations for this purpose.

During loss of grid power, and with or without BESS, PV has the potential to extend stored fuel to enable the backup systems to serve critical loads for longer durations than if PV were not present. To do so, in this type of microgrid application, additional functional requirements are needed. These include an ability to detect and respond to the grid outage by electrically isolating the pumping station loads from the grid, generating the proper electrical signal, and then providing the power level to match station loads. Integrating PV for utilization during grid outages with the existing backup reciprocating engine generators requires examining its potential impact on ramping and loading of the engine generators. Without proper consideration of the potential impact of variable solar resources on the backup generator, critical water service could be jeopardized.

## 3.2 Analysis Assumptions and Inputs

The key assumptions and inputs applied to this analysis are summarized in Table 4 through Table 7.

**Table 4. Economic Parameters**

| Parameter | Value |
|---|---|
| Analysis Period | 25 years |
| Discount Rate, Nominal | 6% |
| General Inflation Rate Applied to Operations and Maintenance Costs | 2.5% |
| Electric Utility Cost Escalation Rate, Nominal | 2.5% |
| Electricity Rate Tariff | $0.20/kWh |
| Compensation for PV electricity exported to the local utility | None |

**Table 5. DER Cost and Assumptions**

| Parameter | Value |
|---|---|
| PV Capital Costs | $850/kW-DC |
| PV Operations and Maintenance Costs | $15/kW-DC/year |
| Battery Capital Costs | $683/kW + $341/kWh |
| Battery Useful Life | 10 years |
| Battery Replacement Costs (Year 10) | $536/kW + $239/kWh |

**Table 6. Technical Parameters**

| Parameter | Value |
|---|---|
| DC-to-AC Ratio | 1.15 |
| Inverter Efficiency | 96% |
| Array Type | Fixed open rack |
| Tilt | 30 degrees |
| Azimuth | 180 degrees |
| Total System Losses | 14.08% |
| Annual Performance Degradation | 0.5%/year |
| Solar Resource File | National Solar Radiation Database 2019 for latitude 50.37 degrees and longitude 24.22 degrees |
| Performance Model | PVWatts® accessed through System Advisor Model |

**Table 7. BESS Technical Parameters**

| Parameter | Value |
|---|---|
| AC-AC Round-Trip Efficiency | 89.9% |
| Initial State of Charge in First Hour of Year-Long Simulation | 50% |
| Minimum State of Charge | 20% |
| Maximum State of Charge | 100% |

# 4 Next Steps

This report is a preliminary, high-level screening. The recommended next steps for Chervonohrad Vodokanal are to share this report with potential funding partners to communicate the goals, potential sizes, costs, and benefits of the system. Once resources are identified, the procurement process will begin to identify and secure a qualified solar PV installation company. Once complete, or as part of the vendor selection process, the installer will perform a site assessment to review locations for installing the solar PV array and balance of system equipment. The installer will also review the electrical infrastructure to determine how to electrically interconnect and whether upgrades may be needed. The site assessment and engineering design will finalize the sizes, system design, and total installation costs. The installer will also work with the local distribution system operator to ensure that each system meets the DSO's technical and regulatory requirements.

# 5 Summary

NREL staff performed a technical and economic analysis for three water pumping stations in Chervonohrad, Ukraine, with support from the U.S. Department of Energy's Net Zero World Initiative and the U.S. Agency for International Development/Ukraine. The analysis finds that integrating PV for parallel operation with the serving power utility is cost-effective at all three pumping stations. Battery energy storage is not found to be cost-effective at any of the sites considering current cost estimates, the structure of the rate tariff, and the presence of existing backup power generators at each site.

# References

Ministry of Energy of Ukraine. 2024. *Action Plan for the Implementation of the Energy Strategy of Ukraine until 2050 (Annex)*. https://mev.gov.ua/sites/default/files/field/file/dodatok-do-proektu-rozporyadzhennya_0.pdf.

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USAID.NREL@nrel.gov

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