Danish Energy Agency

Ministry of Energy of Ukraine

# URGENT TECHNOLOGY CATALOGUE

## For the Ukrainian Power Sector

Edition: May 2025

Danish Energy Agency

Ministry of Energy of Ukraine

Ea Energy Analyses

Institute for Economics and Forecasting of the National Academy of Sciences of Ukraine

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# List of organizations contributing to the expert interviews

This Technology catalogue is made with inputs from many experts from the following Ukrainian, international, and Danish organizations:

- ENERGOINVEST LTD (UA)
- NGO “Ecoclub” (UA)
- MHP Eco Energy (UA)
- Ukrainian Wind Energy Association (UA)
- Bioenergy Association of Ukraine (UA)
- Aalborg Energie Technik (DK)
- Focus Bioenergy (DK)
- Linka Energy (DK)
- Againity (SE)
- MAN Energy Solutions (DK)
- RWE Scandinavia (DK)
- TOWII Renewables (DK)
- Better Energy (DK)
- Hybrid Greentech Energy Intelligence (DK)
- ABB – Hitachi (DK)
- Schneider Electric (DK)
- SGB Smit (DK)
- Siemens Energy (DK)
- BWSC (DK)

# Contents

# 1. Introduction

## 1.1. Background/Context

This catalogue aims to help local, regional, and national stakeholders, developers, companies, and others to prioritize and select relevant power production technologies, outline a framework, determine priorities for technology choices, and attract investments and donor assistance in the restoration and development of the power system of Ukraine in the coming winter seasons.

The first version of the catalogue was published in January 2024. This is the second version.

This technology catalogue seeks to build consensus on power generating technology costs and technical parameters between stakeholders in Ukraine, presenting validated and agreed data for power generating technology in these four newly developed dimensions:

- Power capacity in wintertime
- Implementing speed
- Technology resilience
- Levelized Cost of Electricity (2 years vs full lifetime)

In view of the acute situation of the Ukrainian energy system, this urgent catalogue only includes data on selected technologies and data for the present situation only. Time series data on the past and the future development of technologies over the decades is not included, as they would be in ordinary energy technology catalogues.

## 1.2. The purpose of the urgent technology catalogue

This urgent technology catalogue aims to support decision making at local, regional, and national level across different stakeholders, donors, developers, companies, and authorities.

Therefore, the main focus of this technology catalogue for decentralized power generation technologies is to map their potential for supplying electricity in the current Ukrainian context for winter seasons 2025/26 and 2026/27 that could be implemented to facilitate enhanced security of power supply.

Thus, technologies included in this catalogue are evaluated according to the following four principal criteria:

**Winter impact**, defined as the share of yearly production that can be delivered at wintertime (October to March).

**Potential for rapid plant commissioning (implementation speed).** This involves assessing the following factors: A) Time required for planning and regulatory approvals, B) Time needed for procuring plant components and materials, and C) Duration of technical installation process.

**Resilience of Selected Technologies.** This includes an assessment of the performance at the distribution system level, the potential for camouflage and sheltering, operational requirements (risks and necessary skills), and restoration time (this parameter highlights the ability to quickly resume power generation and was not included in the first version of the catalogue).

**Levelized Cost of Electricity** (LCOE) for electricity supply during the wintertime over a short lifetime (2 years). As background information, to evaluate the economics of the technology in a longer-term perspective, a LCOE for total electricity over the full lifetime is also shown.

Additionally, this urgent technology catalogue includes only technologies that could perform well in relation to the above-mentioned four principal criteria.

The catalogue covers eight types of power generation technologies (listed in the section below). Through a screening process, 23 specific “sub-type technologies” were identified as relevant to evaluate in the current context in Ukraine.

The evaluation of the four principal criteria for the various technologies is supported by an assessment of 15 parameters, which are primarily descriptive and qualitative in nature, as outlined in Table 1. Appendix A: Methodology provides a detailed discussion of these 15 parameters, explaining their relevance to the assessments in this urgent technology catalogue. Additionally, it elaborates on how the qualitative parameters can be evaluated using a three-level scale (good, medium, and poor).

This catalogue represents the second version of the Urgent Catalogue for Ukraine (UTC). The methodology and documentation have been refined, and the evaluations of the technologies have been updated based on additional interviews conducted in the autumn of 2024 with Ukrainian, Danish, and international energy experts and developers. The overarching goal is for the UTC to be a living document, continuously updated and improved over time. While no new technologies have been added to this version, future updates may include additional sub-technologies and/or new types of technologies.

In this version, as a new feature, descriptions of initiatives that could improve especially the resilience and speed of implementation are included in separate sections.

## 1.3. Technologies included in the evaluation of The Urgent Technology Catalogue

The following technologies are assessed:

1. Gas power plants
   - Gas Turbines, simple cycle, natural gas
   - Gas engines, natural gas
   - Gas engines, biogas directly from a green field biogas plant
2. Photovoltaics (PV)
   - Rooftop PV on single family houses
   - Rooftop and ground mounted PV on public buildings (incl. hospitals) with batteries
   - PV utility scale, ground mounted without batteries
   - PV utility scale, floating, e.g., on hydropower dams (here the hydro dams can be regarded as storage, but are not included)
3. Wind turbines
   - Onshore wind turbines, farms 20-100 MW

- Onshore wind turbines, farms 20-100 MW, used turbines
- Onshore wind, cluster of 3-5 turbines 3-20 MW
- Household (domestic) wind turbines 1-30 kW

4. Coal power plants, lifetime extension (replacement of equipment)
   - Retrofitting existing plants, improving efficiency
5. Batteries – Lithium-ion not small-scale BESS
   - Grid-scale batteries (capacity app. 2-150 MW, energy storage 2-500 MWh)
   - Community batteries (capacity app. 40-150 kW, energy storage app. 40-600 kWh)
6. Biogas
   - Production of biogas is only included as fuel for the gas engine. Therefore, no criteria evaluation is conducted for biogas
   - No specific sub-technologies have been identified during the screening, but a gas engine fuelled by biogas is included as a part of gas power technologies
7. Biomass cogeneration (CHP) technologies
   - Wood pellets medium, back pressure, 25 MWe
   - Wood pellets small Organic Rankine Cycle, 3 MWe
   - Wood chips, medium, back pressure, 25 MWe
   - Wood chips, small Organic Rankine Cycle, 3 MWe
   - Straw/stalks/husk small Organic Rankine Cycle, 3 MWe
   - Straw/stalks/husk medium, back pressure, 25 MWe
8. Hydro Power
   - Small, Hydro Power, run-of-river
   - Mini, Hydro Power, run-of-river
   - Retrofit hydropower (dams), incl. pumped hydropower storage

# 2. Methodology

The qualitative and quantitative parameters addressed in this urgent technology catalogue are based on the information gathered through semi-structured interviews with Ukrainian, Danish, and international energy experts and developers. In addition, Ukrainian authorities, associations, and organizations working in the energy sector and its supply chains have been consulted during the process.

Based on the outcomes of the interviews, the typical process for power plants' installation, expected bottlenecks, and realistic possibilities to speed up the implementation process under the current conditions are described and analysed according to the parameters.

In addition to the information obtained through interviews, data from the Danish Energy Technology Catalogues adjusted to the Ukrainian context, have been applied, along with evidence about wind, solar, and hydro resources in Ukraine from public sources and information gathered from literature sources and websites of manufacturers.

## 2.1. Assessment of parameters and criteria

The assessment of technologies assumes a greenfield project approach, meaning the projects are developed from scratch with no prior site preparation or project development. The equipment used is also assumed to be new.

However, implementation speed could benefit if projects could build on existing development efforts, such as those already in progress or approved before the war, or if facilities are established as replacements for destroyed infrastructure. The use of second-hand equipment could also be advantageous. Unfortunately, identifying such pre-developed projects or potential replacement opportunities was not feasible within the timeframe of this study. Should any of these opportunities be relevant to a specific technology assessment, they will be explicitly noted.

An overview of the **15 parameters** that are discussed and assessed in this technology catalogue is presented in Table 1.

A description of the 15 parameters is given in Appendix A: Methodology. The appendix accounts for the reasons for addressing each parameter in this technology catalogue and how they influence the implementation of power generation projects in the current Ukrainian context. Following this, the three-level assessment scale specific to each of these parameters is described.

Each of the 15 parameters contributes to one of the four principal criteria. To give a comprehensive overview, this is shown both in Table 1 and in Table 2.

*Table 1: Overview of the evaluation parameters and definition of the levels, the 'Criteria' column indicates which of the four principal criteria the parameter contributes to, as indicated by the letter." (W, Q, R or C) in the. W: Winter Impact, Q: Implementation speed (Quick), R: Resilience in operation in UA.*

** Each technology is rated on a scale from 1 to 10 for each parameter. Scores of 1 to 3 indicate the lowest category, 4 to 7 the medium category, and 8 to 10 the highest category*

*** Special transport of some components or the full for the technology.*

| Parameters | Criteria | Evaluation levels: | | |
|---|---|---|---|---|
| | | Good | Medium | Poor |
| **Parameter score *** | | 8-10 | 4-7 | 0-3 |
| P1-Electricity production capacity at wintertime | W | >75% | 40-75% | <40% |
| P2-Levelized Cost of Electricity (LCOE) short lifetime, winter production | C | 25% lower than average, <1 150 €/MWh | 75-125% of average, 1 150-1 900 €/MWh | 25% more expensive than average, >1 900 €/MWh |
| P3-Levelized Cost of Electricity (LCOE) over lifetime | | 25% lower than average, <90 €/MWh | 75-125% of average, 90-150 €/MWh | 25% more expensive than average, >150 €/MWh |
| P4-Distributed generation | R | <5 MW, high location flexibility | 5-20 MW, moderate location flexibility | 20-60 MW, reduced location flexibility. |
| P5-Regulation requirement in the project development process | Q | 3 months or less | 3-9 months | 9 months or more |
| P6-Delivery time and availability of components and materials | Q | 3 months or less | 3-14 months | 14 months or more |
| P7-Requirements for logistics and transportation infrastructure | Q | Transport on a normal-size lorry possible | Special transport necessary* | Special transport and reinforcement/construction of new roads necessary |
| P8-Technical installation time (after clearance) | Q | Less than 3 months | 3-9 months | More than 9 months |
| P9-Requirements for skilled staff in construction phase | Q | Only need for few and/or non-specialized labour for installation | Need for a moderate number of skilled workers | Need for a large workforce and/or highly specialized labour |
| P10-Grid balancing capacity | R | High ability to balance the system | Medium ability to balance the system | Low ability to provide balancing services to the grid system |
| P11-Requirements for electricity grid infrastructure | Q | Easy to connect | Moderate connection requirements | Highly connect requirement |
| P12-Requirements for skilled staff for operation and maintenance and for special spare parts | R | Minimal reliance on specialized staff and spare parts | Some reliance on skilled staff and specific spare parts | Significant reliance on skilled technicians and hard-to-source spare parts |
| P13-Possibility for camouflage and sheltering | R | High | Medium | Low |
| P14-Risk associated with fuel supply | R | Low risk | Medium risk | High risk |
| P15-Restoration time | R | 3 months or less | 3-14 months | 14 months or more |

The **four principal criteria** are shown in Table 2. The criteria are W: **W**inter Impact, Q: Implementation speed (**Q**uick), R: **R**esilience in operation in UA context, and C: **C**ost of generating the electricity (referred to as Levelized Cost of Electricity (LCOE).

Some parameters are assigned absolute values (e.g., duration in weeks, LCOE in €/kWh), while this is not possible for other parameters. In the latter cases, the parameters are given an assessment as a number between 1 and 10, to make it possible to evaluate the criterion by calculating the average and weighted value.

For the overall results of each criterion and the general score, it is important to note that the scoring system varies depending on the criterion. In some cases, a lower score is preferable, while in others, a higher score is better. To provide a clear and consistent summary (referred to as the general score), the results are displayed using a “more icons, the better” format.

An overview of which parameters contribute to which criteria is shown in Table 2 in column “Parameter”.

*Table 2: Overview of the parameters contributing to each criterion, along with the corresponding ratings.*

| Indicator | Parameter | Poor | Medium | Good |
|---|---|---|---|---|
| Capacity in wintertime[1] | P1 | Low production capacity in wintertime | Medium production capacity in wintertime | High production capacity in wintertime |
| Implementation speed[2] | P5, P6, P7, P8, P9, P11 | Long timeframe | Medium timeframe | Short timeframe |
| Resilience[3] | P4, P10, P12, P13, P14, P15 | Low resilience | Medium resilience | High resilience |
| Levelized Cost of Electricity[4] | P2, (P3) | High costs | Medium costs | Low costs |

The number of icons represents the quality of the rating with more icons indicating a better rating.

## 2.1.1. Criteria

Some criteria, such as **Winter Impact (W)** and **Levelized Cost of Energy (LCOE) (C)**, consist of only one parameter making their evaluation straight forward. In contrast, the criteria **Implementation Speed (Q)** and **Resilience (R)** are evaluated based on six parameters each.

1 Winter impact, defined as share of yearly production that can be delivered during wintertime (October to March)

2 Implementation speed which is the possibility for bringing in operation within a short timeframe.

3 Resilience of selected technologies which is how well the technology perform at distribution system level, how well it could be camouflaged and sheltered, risk for fuel supply, and level of requirement (risks and skills) for keeping it in operation.

4 For electricity supply during the wintertime over a short lifetime (2 years). Furthermore, LCOE for total electricity over the full lifetime, is shown as a parameter (3). This LCOE information makes it possible to evaluate for the time after the war ends.

### Implementation Speed (Q)

Implementation speed (Q) is evaluated based on both time-related factors and additional parameters that influence the overall pace of project development. These factors are represented by six parameters, divided into two categories:

Time-quantified parameters: P5-*"Regulation requirements in the project development process"*, P6-*"Delivery time and availability of components and materials"*, and P8-*"Technical installation time (after clearance)."* These parameters are measured in weeks then converted into months and hereafter they are given a parameter score (1-10) as described in Appendix 9.1. Overlapping phases are considered during evaluation to ensure a realistic timeline.

Qualitative parameters: P7-*"Requirements for logistics and transportation infrastructure"*, P9-*"Requirements for skilled staff during the construction phase"*, and P11-*"Requirements for electricity grid infrastructure."* These parameters are assessed qualitatively, with technologies ranked relative to one another based on their complexity and resource needs.

To provide a balanced evaluation, each parameter is assigned a specific weight according to its impact on implementation speed. Overview of the parameter weighting for the implementing speed criteria is shown in Table 3.

*Table 3: Parameter weighting for the Implementing speed criteria.*

| Criteria | Implementation Speed |
|---|---|
| Weight | Parameter |
| 20% | P5-Regulation requirement in the project development process |
| 20% | P6-Delivery time and availability of components and materials |
| 10% | P7-Requirements for logistics and transportation infrastructure |
| 20% | P8-Technical installation time (after clearance) |
| 20% | P9-Requirements for skilled staff in construction phase |
| 10% | P11-Requirements for electricity grid infrastructure |

The following explains the weighting of the parameters:

Time-quantified parameters such as P5-*"Regulation requirement in the project development process"*, P6-*"Delivery time and availability of components and materials"*, and P8-*"Technical installation time (after clearance)"* are weighted with 20% each.

While for the qualitative parameters, P7-*"Requirements for logistics and transportation infrastructure"*, which include considerations about whether projects require specialized transport or new infrastructure, are weighted 10%, even though these challenges for transportation are partly reflected in P6.

Furthermore, High labour demand can significantly delay implementation, especially in Ukraine, where labour shortages are an increasing problem. Therefore, parameter P9-"Requirements for skilled staff during the construction phase" is weighted by 20%.

Connecting to the grid is often time-consuming, therefore the parameter P11-*"Requirements for electricity grid infrastructure"* accounts for 10% of the overall weighting for implementing speed.

By combining these weighted parameters, the implementation speed criterion provides a comprehensive assessment of the factors influencing the timeline and feasibility of project development.

### Resilience (R)

When evaluating Resilience (R), there are no absolute values with the same unit for all six parameters influencing the criteria. Therefore, each technology is evaluated relative to the performance of other technologies for these six parameters. Subsequently, when adding up to the criterion the six parameters are given different weights relative to their importance. The weight of each parameter has been reassessed since the last publication of the catalogue, based on developments in Ukraine over the past year and including the information collected during interviews in 2024. Overview of the parameter weighting for the resilience criteria is shown in Table 4.

*Table 4: Parameter weighting for the resilience criteria.*

| Criteria | Implementation Speed |
|---|---|
| Weight | Parameter |
| 25% | P4-Distributed generation |
| 10% | P10-Grid balancing capacity |
| 10% | P12-Requirements for skilled staff for operation and maintenance |
| 15% | P13-Possibility for camouflage and sheltering |
| 30% | P14-Risk associated with fuel supply |
| 10% | P15-Restoration time |

The following explains the weighting of the parameters:

P4-*"Distributed generation"* is assessed as the most important parameter and is therefore given a weight of 25%. This reflects the advantages of decentralized energy systems that are less vulnerable to large-scale attacks.

P14-"*Risk associated with fuel supply"* is assigned a weight of 30%, an increase from the previous version of the catalogue. This change is due to Ukraine's evolving fuel security situation, particularly regarding gas supply and infrastructure vulnerability, making this factor increasingly critical.

P10-*"Grid balancing capacity"* weighted at 10% and have not been changes since the previous version of the catalogue.

P13-*"Possibility for camouflage and sheltering"* is weighted at 15%. However, the weight for P13 has been reduced. While it is still important for protection against aerial threats, the effectiveness of camouflage is limited against sophisticated drone swarms and missile attacks, justifying the reduced weight. It is important to note that for P13-"Possibility for camouflage and sheltering", the evaluation only assesses how easily the technology can be camouflaged or sheltered, such as by covering it with a concrete lid or using an anti-drone net. The assessment focuses on the physical configuration of the technology and does not evaluate the types of attacks the shelters can withstand.

P15-*"Restoration time"* is a new parameter added to the criteria and is given a weight of 10%. This emphasizes the importance of quickly restoring power generation, with modular technologies offering significant advantages in minimizing downtime and restoring grid functionality.

P12-*"Requirements for skilled staff for operation and maintenance and for special spare parts"* is also weighted at 10%. This remains a crucial consideration due to the increasing problem of workforce shortages.

## 2.1.2. General score

The General score is calculated as the simple average of the four criteria as illustrated in Figure 1. Furthermore, the general score excluding cost (LCOE) is shown to make it possible to make the evaluation without taking the cost into consideration[5].

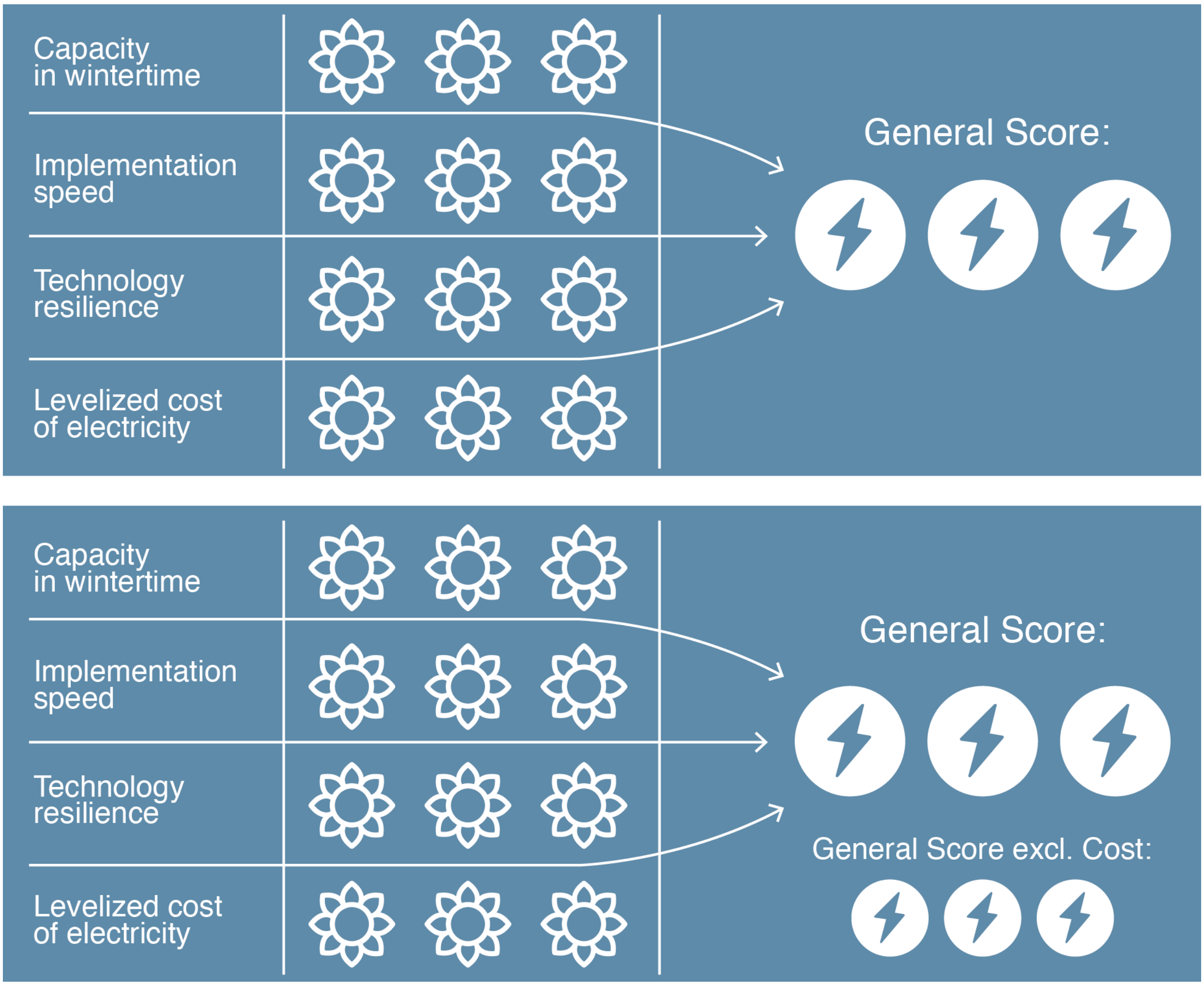



*Figure 1: Example I. Visualization of criteria and general score – the more stars the better rating*

## 2.2. LCOE calculations

The method is described in Appendix B: LCOE calculations.

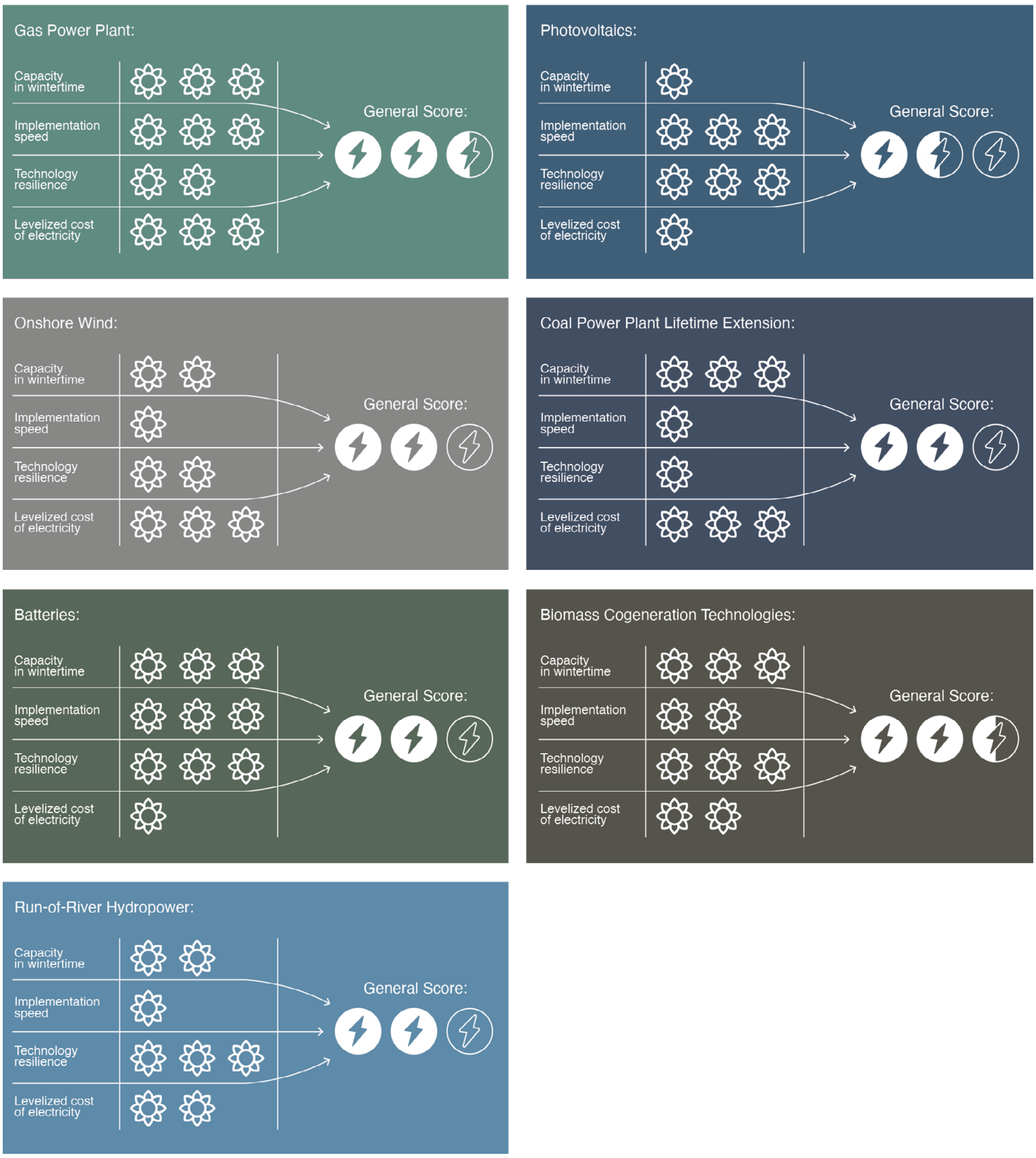
## 2.3. Technology front page

On each front page for a technology chapter, the result of the criteria evaluation is displayed for the best sub-technology in the chapter. The criteria evaluation is represented graphically with the icons shown in Table 2 and Figure 1.

5 The General score not including the LCOE score was requested in feedback for the version 1 of this catalogue.

# 3. The Overall Findings of the Evaluations, Technology summaries

Figure 2 presents an overview of the evaluation of the highest rated technology within each of the categories. The more icons the better rating.



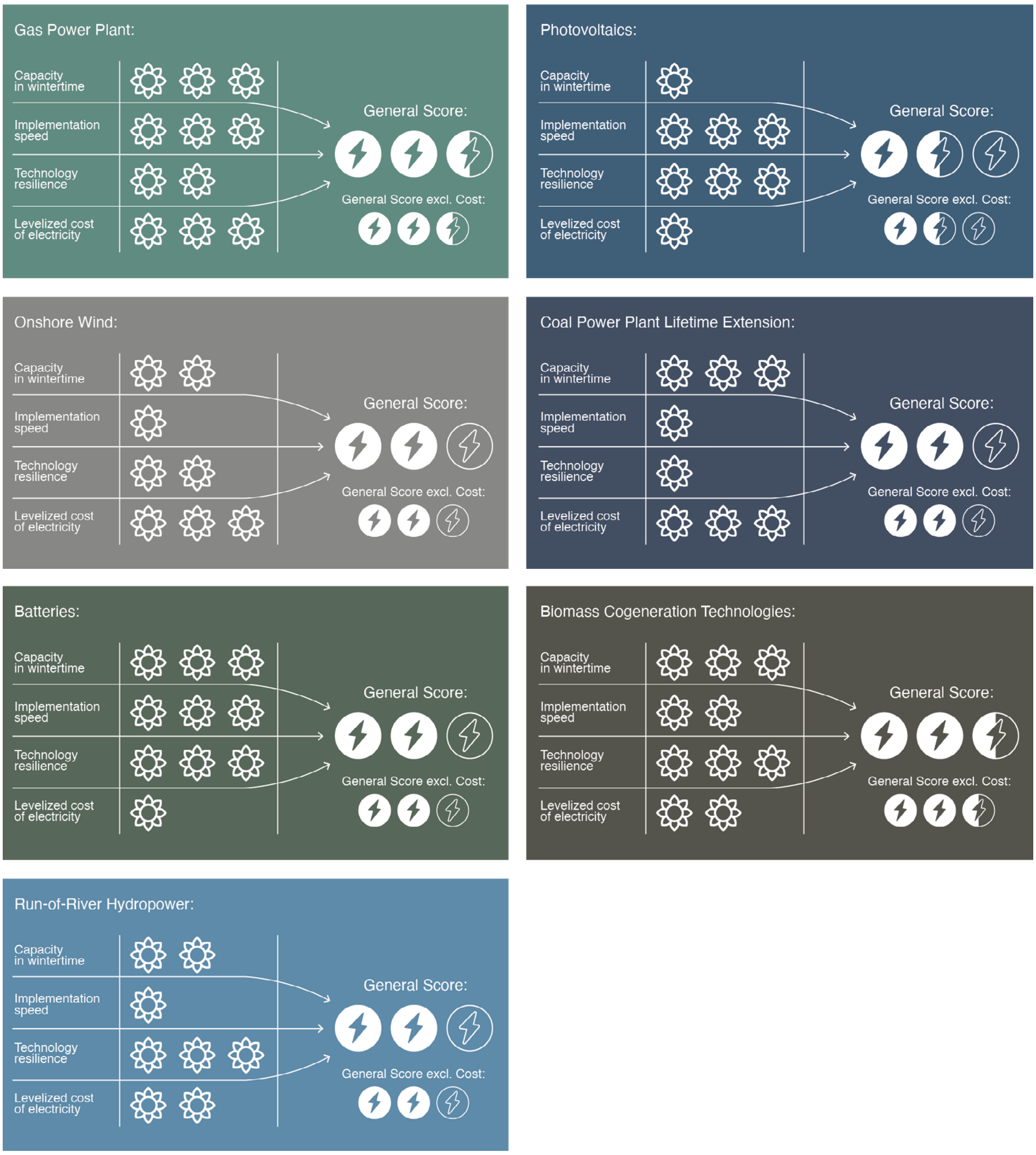



*Figure 2: Technology summaries of the best technologies in each category (Gas engines, Rooftop PVs household, commercial and industrial, Onshore wind turbines, farms >20MW, Coal power plants retrofitting, Li-ion batteries on community scale, biomass CHP medium wood pellets, Hydro RoR micro).*

Table 3 provides a comprehensive evaluation of the sub-technology level, focusing on the four principal criteria.

**On general score:**

Gas engines fuelled by natural gas outperform the others, securing the highest overall score. The small size biomass pellet CHP using an Organic Rankin Cycle (ORC) also performs well.

**On Wintertime Production:**

Gas turbines, gas engines, other thermal plants, batteries, and large hydro power plants with dams pose the greatest potential for supplying energy during wintertime, contrary to for example solar PV whose performance is limited during the winter season. For batteries, it is of course a prerequisite that they have access to a regular electricity supply over the winter in order to be able to deliver.[6]

**On Implementing Speed:**

Gas engines, rooftop PV, household wind turbines, batteries and retrofitting or repair of HPPs with dams could be implemented within half a year, while gas turbines, large PV, used onshore wind turbines, small size biomass CHPs, and retrofitted coal are deemed realistic for implementation by 2025-2026 due to short approval processes, no or limited need for special transportation and shorter construction timelines. In contrast, other technologies face longer timelines exceeding 1.5 years due to complex approval procedures and extended delivery or installation/construction times. This applies, for example, to onshore wind, medium size biomass CHP, small size hydro power plants (RoR), and biogas engines (that are exclusively supplied with fuel from the associated greenfield project biogas plant).

Reducing the implementation timeline for large wind turbine projects is feasible by relaxing environmental impact assessment requirements. Under ideal conditions, including the use of used wind turbines, projects could potentially be established within 1.5 to 2 years, emphasizing the importance of regulatory flexibility for sustainable energy solutions.

**On Technology Resilience:**

Small bio CHP (ORC), and small and mini/micro RoR HPPS also demonstrate a high level of resilience since they can be sheltered and protected more effectively due to their smaller size, flexibility in location, low or moderate restoration time, and low or moderate risk associated with fuel supply. The same is true for community scale batteries. Resilience has also been deemed high for small and medium scale PV and household wind turbines because due to their size, they are not seen as important targets.

**On Cost (LCOE):**

When considering the cost effectiveness (LCOE) of the technologies over a short time and only for the winter production gas technologies, onshore wind, coal retrofitting, and medium size wood pellets CHP turn out to be the most cost efficient.

When calculating the LCOE over the full lifetime of the technology, including the total electricity production, the most cost-effective solutions are large-scale wind farms, hydro power plants, and PV. These technologies are renewable and have no fuel cost and low maintenance and operating costs. This contributes to a low LCOE over their total operational lifetime.

**On General scores (excl. cost):**

Gas power using natural gas, household wind turbines, batteries, and biomass CHP plants achieve the highest scores if LCOE is omitted from the criteria assessment.

**Additionally:**

Additionally, for most technologies, the connection of the plant to the grid via transformers is a critical component. As a result, the delivery time for transformers is also a key parameter for many technologies. Stakeholders have indicated that the current delivery time for transformers ranges from 40 weeks to 2 years, though there are ways

[6] The full value of battery storage systems relies on the daily availability of untapped energy production potential. This includes opportunities to shift electricity from low-demand periods (such as winter nights to daytime hours in winter) or periods of high renewable energy generation (e.g., solar power in summer) to high-demand periods (such as peak cooking times). By optimizing energy storage and distribution in this way, batteries can maximize their contribution to grid stability and efficiency.

to expedite this process. While a two-year delivery time poses a risk, this time frame has not been assumed in the evaluations.

The tables below provide a comprehensive evaluation of the sub-technology level, focusing on the four principal criteria.

*Table 5: For implementation speed, the colour coding indicates the following: Green: The technology could be operational in less than 0.5 years. Yellow: The technology could be operational within 1-1.5 years. Red: It would take more than 2 years to bring the technology into operation.*

| Criteria evaluation | 1.a. Gas turb. simple cycle, NG | 1.b. Gas engines, NG | 1.c. Gas engines, biogas | 2.a. PV residential rooftop | 2.b.5.b PV comm. & industrial – with battery | 2.b. PV comm. & industrial | 2.c. PV utility scale, ground mounted | 2.d. PV utility scale, floating |
|---|---|---|---|---|---|---|---|---|
| Winter impact | WWW | WWW | WWW | W | W | W | W | W |
| Implementing speed | QQ | QQQ | Q | QQQ | QQQ | QQQ | QQ | Q |
| Resilience | R | RR | R | RRR | RRR | RRR | RRR | RRR |
| Cost (LCOE, wintertime 2 years lifetime) | CCC | CCC | CCC | C | C | C | CC | CC |
| General score (1-3) | 2.4 | 2.5 | 2.2 | 1.7 | 1.6 | 1.5 | 1.7 | 1.5 |
| General scores (excl. cost) (1-3) | 2.2 | 2.5 | 2.0 | 2.1 | 2.1 | 2.0 | 1.6 | 1.6 |

| Criteria evaluation | 3.a. Wind onshore farms (>20 MW) | 3.b. Used wind onshore farms (>20 MW) | 3.c. Wind onshore cluster (4.2-20 MW) | 3.d. Wind household turbines (<100 kW) | 4. Coal retrofitting | 5.a. Bat, Li-ion utility scale | 5.b. Bat, Li-ion community scale |
|---|---|---|---|---|---|---|---|
| Winter impact | WW | WW | WW | WW | WWW | WWW | WWW |
| Implementing speed | Q | Q | Q | QQQ | Q | QQ | QQQ |
| Resilience | RR | RR | RR | RRR | R | RR | RRR |
| Cost (LCOE, wintertime 2 years lifetime) | CCC | CCC | CCC | C | CCC | C | C |
| General score (1-3) | 2.0 | 2.1 | 2.0 | 1.9 | 2.1 | 1.9 | 2.0 |
| General scores (excl. cost) (1-3) | 1.8 | 1.9 | 1.9 | 2.4 | 1.9 | 2.4 | 2.6 |

| Criteria evaluation | 7.a. Wood pellets, CHP medium | 7.b. Wood pellets, CHP Small | 7.c. Wood Chips, CHP Medium | 7.d. Wood Chips, CHP Small | 7.e. Straw/ stalks/ husk, CHP Medium | 7.f. Straw/ stalks/ husk, CHP Small | 8.a. Hydro, RoR, small | 8.b. Hydro, RoR, micro | 8.c. Retrf Hydro power, dams incl. PHS |
|---|---|---|---|---|---|---|---|---|---|
| Winter impact | WWW | WWW | WWW | WWW | WWW | WWW | WW | WW | WW |
| Implementing speed | Q | QQ | Q | QQ | Q | QQ | Q | Q | QQ |
| Resilience | RR | RRR | RR | RRR | RR | RRR | RRR | RRR | R |
| Cost (LCOE, wintertime 2 years lifetime) | CCC | CC | CC | CC | CC | CC | CC | CC | n.a |
| General score (1-3) | 2.3 | 2.4 | 2.2 | 2.4 | 2.2 | 2.4 | 1.6 | 1.8 | n.a |
| General scores (excl. cost) (1-3) | 2.3 | 2.5 | 2.3 | 2.5 | 2.3 | 2.5 | 1.8 | 1.8 | 2.0 |

# 3.1. Details for the four principal criteria

Cross-cutting issues, such as challenges related to the grid, operational difficulties within Ukraine's grid system, the integration of renewable energy technologies, financial constraints, and transformer-related concerns, are detailed in Appendix C.

## 3.1.1. Winter impact (production at wintertime) (W)

Wintertime is in this context October to March (both months inclusive).

Thermal power plants that include gas, coal, and biomass-based systems, achieve the highest performance scores for the ability to produce during the wintertime. The primary reason for this is their dispatchability — the ability to adjust power output as demand or availability of energy supply changes. Unlike renewable sources, these plants can increase or decrease production based on demand, making them highly reliable during the winter months when energy demand often spikes.

The efficiency of wind and hydroelectric power systems can be influenced by seasonal weather patterns, but in general, both technologies demonstrate a fairly high availability during the winter season leading to a medium score.

Battery storage systems also receive a high score, but for different reasons. The performance of these systems largely depends on the grid system they are integrated with, specifically whether there is sufficient capacity for them to charge during off-peak hours. If grid capacity is insufficient, batteries may not be able to store enough energy for use during peak demand periods, reducing their effectiveness.

Lastly, solar photovoltaic (PV) systems tend to perform the worst during the winter months. Shorter daylight hours and the lower position of the sun in the sky reduce the amount of sunlight that solar panels can convert into electricity. Additionally, snow and ice can cover panels, further decreasing their output. As a result, solar PV systems are often less reliable during the winter, leading to their lower performance score.

## 3.1.2. Implementation speed (Q)

When it comes to the speed of implementation, gas engines, small photovoltaic (PV) systems (household and community scale), household wind turbines, and community scale battery storage systems achieve the highest ratings. These technologies can be deployed relatively quickly due to their mature technology, streamlined approval processes, the availability of off-the-shelf solutions, and no need for specialized transportation.

Onshore wind farms, small biomass combined heat and power (CHP) technologies, coal retrofitting projects, and micro run-of-river hydro systems receive a medium rating. The implementation of these technologies involves more complex procedures, including regulatory compliance, planning, and construction, which can extend the deployment timeline.

The small run-of-river hydro systems, onshore wind turbines, and medium size biomass CHPs receive the lowest rating in terms of implementation speed. These projects often involve significant regulatory hurdles and lengthy planning processes that can delay their implementation. Gas engines which are exclusively supplied with fuel from the associated greenfield project biogas plant are also the lowest rating in terms of implementation speed due to a significant regulatory and planning process and a complicated installation process for the biogas plant.

As illustrated in Figure 3, the time required for regulatory compliance, environmental survey, and planning is particularly significant for onshore wind and small run-of-river hydro projects. These stages can considerably extend the overall implementation timeline for these technologies.

In general, small-scale technologies, such as rooftop PV systems and household wind turbines, can be deployed most rapidly. Their small size simplifies the approval and installation procedures, and these technologies are often available off-the-shelf. This contrasts with larger, megawatt-scale technologies that are typically custom-built for specific projects, extending the time from order to operation.

The application of reused technologies could expedite the implementation process. For instance, in the case of wind turbines and gas engines, reusing components or entire systems from decommissioned or upgraded projects can reduce both the time and cost associated with the deployment of these systems. Furthermore, the implementation timeline for wind turbine projects could be significantly shortened if the requirements for environmental impact assessments were relaxed. These assessments, while crucial for ensuring the sustainability and environmental compatibility of these projects, are highly time-consuming.

## Implementing speed (Q) assesment

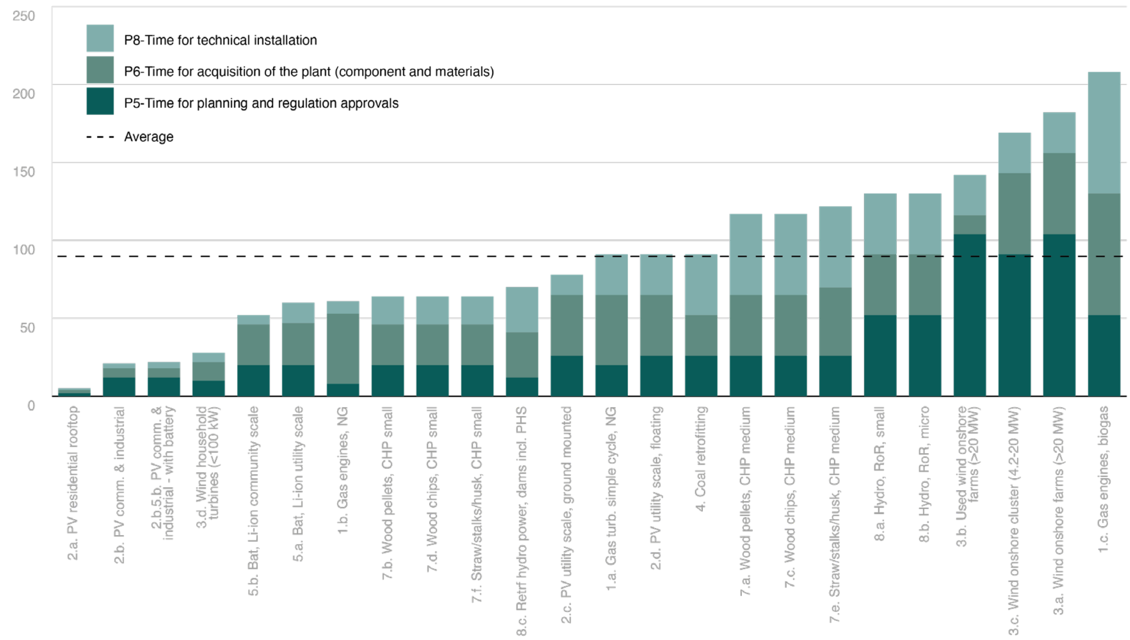



*Figure 3: Assessment of the implementing speed measured in weeks*

## 3.1.3. Resilience (R)

The resilience of energy technology is largely determined by its scale and distribution. Distributed technologies tend to be more resilient due to their ability to withstand and recover from disruptions. An overview of the resilience of the sub-technologies is shown in Figure 4.

Since the last publication of the urgent technology catalogue, resilience has become increasingly critical due to Russia's ongoing large-scale attacks on Ukraine's energy infrastructure. In response, an additional analysis was conducted to optimize the assessment of technology resilience. This resulted in the inclusion of a new parameter, Restoration Time, and reweighting of existing parameters to better reflect the current challenges.

The revised methodology emphasizes distributed energy systems, fuel supply security, and grid stability, while introducing a stronger focus on minimizing restoration time to ensure rapid recovery.

Coal power plants have been given the lowest score in terms of resilience. Power plants offer high energy production concentrated in one location, this centralized nature makes them more vulnerable to disruptions. A single attack could potentially take out the entire plant, significantly impacting power supply.

On the other end of the spectrum, solar panels and battery storage systems receive the highest rating. These systems are less vulnerable due to their smaller size and flexibility in location. Solar panels' modular nature contributes to their resilience, as damage to one part of the system does not necessarily impact the entire network.

Other small-scale technologies, such as household wind turbines, also receive high scores. While household wind turbines could potentially be damaged by enemy artillery, drones, or missiles, they are not typically considered high-value targets due to their small size and distributed nature. Furthermore, they can be located close to consumption, minimizing the reliance on the electricity grid, and making the technologies less vulnerable to attacks.

Large-scale wind and solar farms also receive high scores due to their dispersed layout that would require multiple attacks to incapacitate them completely. Additionally, transformer stations linking these farms to the high-voltage power grid can be camouflaged or protected, for instance, with concrete shielding.

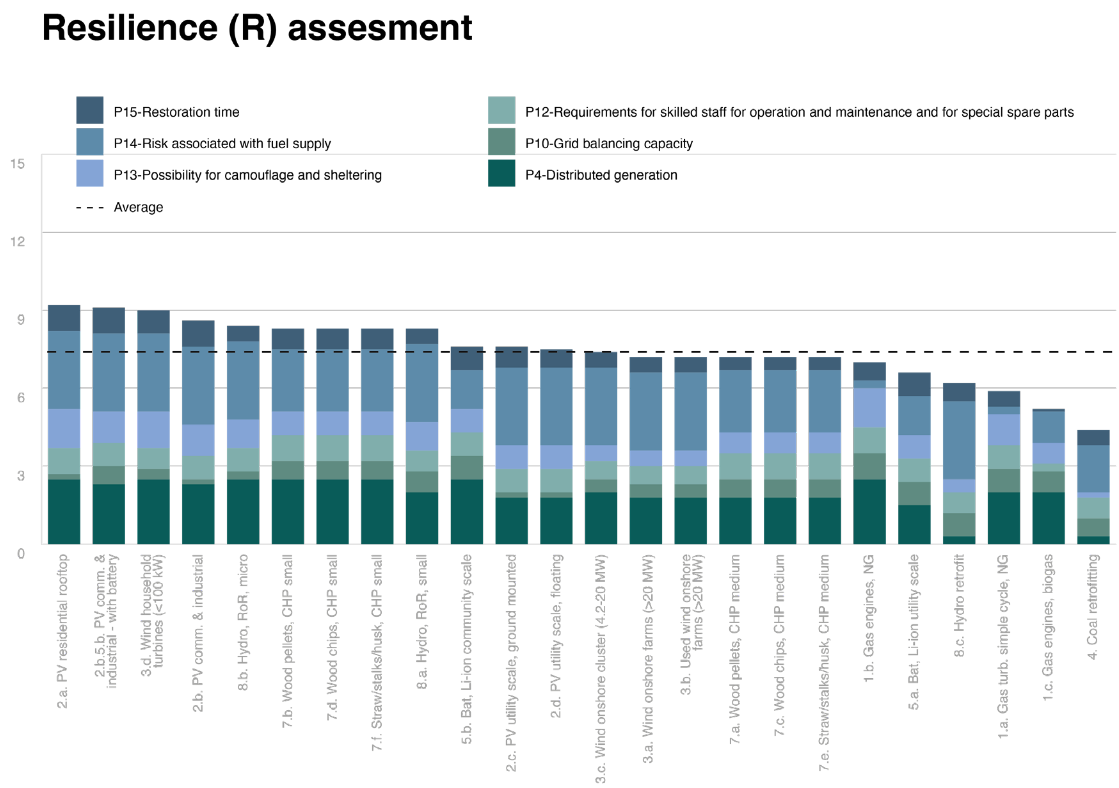



*Figure 4: Overview of the resilience assessment for all sub-technologies. The parameters are weighted, with the most resilient technology receiving the highest score and positioned furthest to the left. Conversely, the lowest-performing technology has the lowest score and is placed furthest to the right*

## 3.1.4. LCOE (C)

The Levelized Cost of Electricity (LCOE) is a crucial metric in assessing the economic viability of different electricity generation technologies. It represents the per-megawatt-hour cost (in real Euro) of building and operating a generating plant over an assumed financial life and duty cycle.

In this criteria analysis, the LCOE is evaluated over two winter seasons as well as over the full lifetime of the technologies. The results are shown in Figure 5.

In the short term, specifically over two winter seasons, gas turbines and gas engines demonstrate the lowest LCOE. This is primarily due to their high production capability during the colder months and their relatively low initial investment costs. Following gas technologies, other large-scale thermal generation technologies and onshore wind power also exhibit competitive short-term LCOEs.

On the other hand, all solar power technologies, household wind turbines, and batteries exhibit high short-term LCOEs. For PV, this is due to their limited power generation capacity during the winter months, coupled with their high initial investment costs. For batteries, it is due to their high initial investment cost.

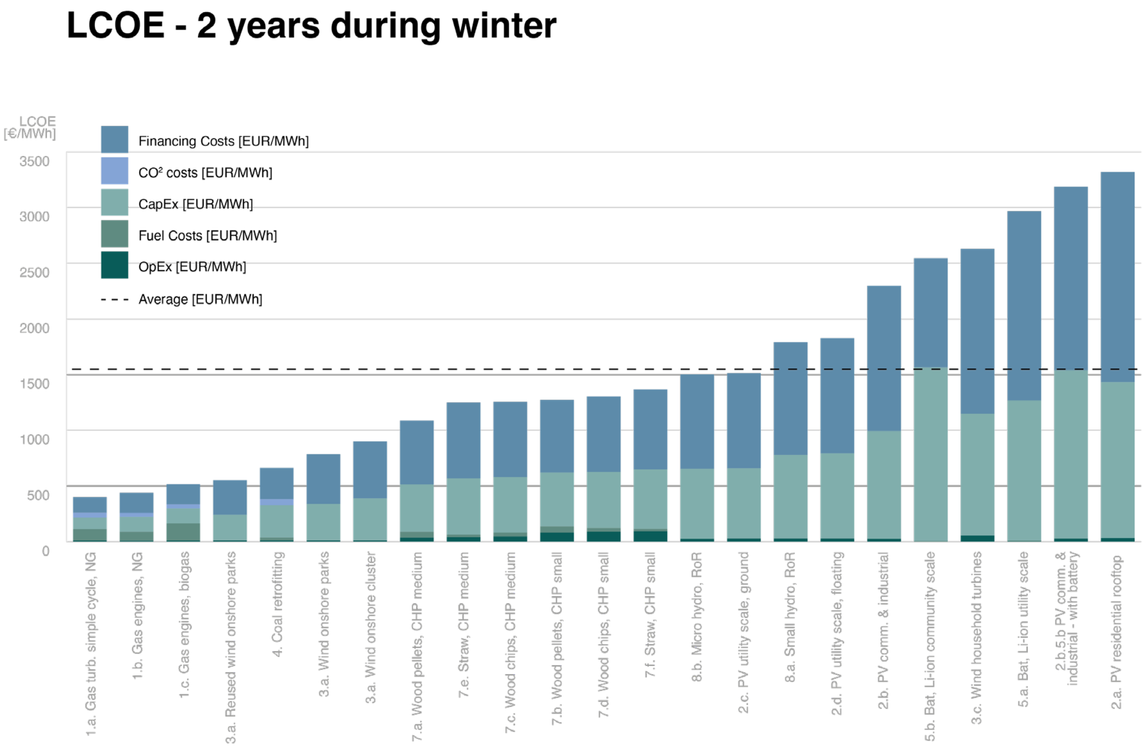



*Figure 5: LCOE for wintertime production over 2 years*

When considering the LCOE over the full lifetime of the technologies[7], shown in Figure 6, the picture changes. Large-scale wind and all solar power plants, along with hydroelectric power, emerge as the most cost-effective solutions. These technologies, while requiring significant initial investment, offer substantial returns over their operational lifetime due to their renewable nature and low operating costs.

Following these, medium size biomass CHP and gas engines using natural gas also demonstrate competitive lifetime LCOEs.

The remaining thermal power plants, as well as batteries and household wind turbines, exhibit relatively high Levelized Costs of Energy (LCOEs). These technologies face challenges such as high fuel costs (in the case of thermal plants) and high investment costs relative to their energy output (for batteries and household wind turbines), leading to elevated long-term costs. Specifically, for community-scale batteries, the LCOE over their full lifetime is particularly high, as a lifespan of only 10 years is assumed.

[7] Including financial cost (WACC) for all technologies and cost of CO2 for fossil fuel.

**LCOE - Full Lifetime**

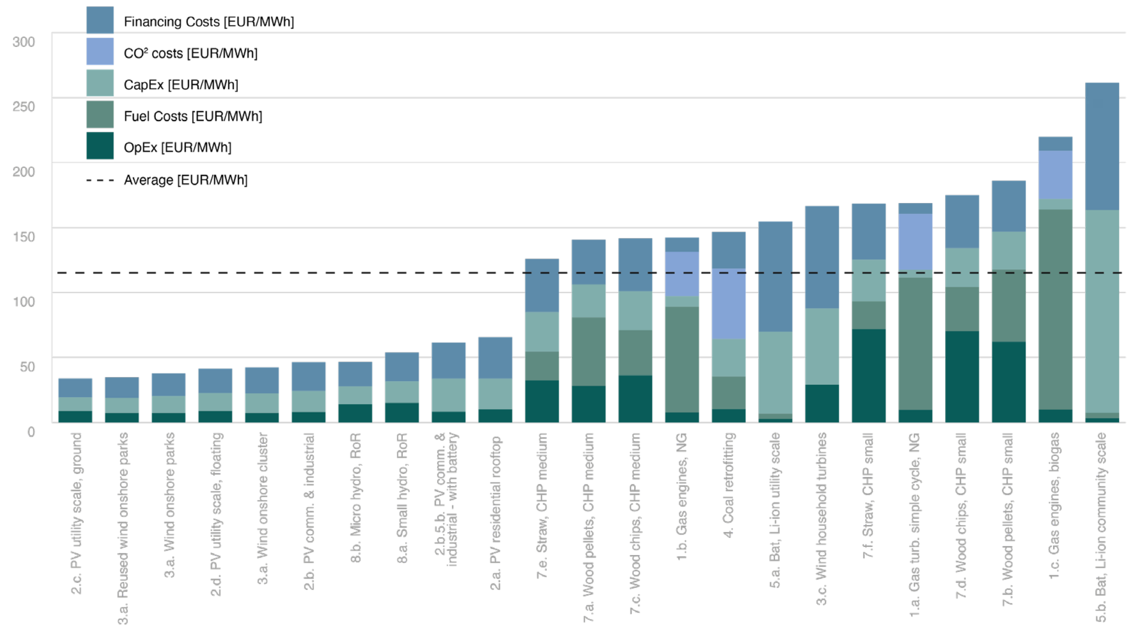



*Figure 6: LCOE against total production over the lifetime*

## 3.1.5. Parameter evaluation overview

*Table 6: Parameter evaluation matrix.*

| Criteria evaluation | 1.a. Gas turb. simple cycle, NG | 1.b. Gas engines, NG | 1.c. Gas engines, biogas | 2.a. PV residential rooftop | 2.b.5.b PV comm. & industrial – with battery | 2.b. PV comm. & industrial | 2.c. PV utility scale, ground mounted | 2.d. PV utility scale, floating |
|---|---|---|---|---|---|---|---|---|
| P1-Electricity production at wintertime | >75% | >75% | >75% | <30% | <30% | <30% | <30% | <30% |
| P2-Levelized Cost of Electricity (LCOE) short lifetime, winter production [€/MWh] | 356 | 405 | 479 | 3 320 | 3 187 | 2 300 | 1 512 | 1 828 |
| P3-Levelized Cost of Electricity (LCOE) over lifetime [€/MWh] | 169 | 142 | 220 | 66 | 62 | 46 | 34 | 41 |
| P4-Distributed generation | Good | Good | Good | Good | Good | Good | Medium | Medium |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| P5-Regulation requirement in the project development process | In between | Quick and easy | Lengthy | Quick and easy | Quick and easy | Quick and easy | In between | In between |
| P6-Delivery time and availability of components and materials | In between | In between | Lengthy and complicated | Quick and easy | Quick and easy | Quick and easy | In between | In between |
| P7-Requirements for logistics and transportation infrastructure | Low | Low | Low | Low | Low | Low | Low | Low |
| P8-Technical installation time (after clearance) | Medium-term | Quick and easy | Lengthy and complicated | Quick and easy | Quick and easy | Quick and easy | Quick and easy | Medium-term |
| P9-Requirements for skilled staff in construction phase | Low | Low | Medium | Low | Low | Low | Low | Low |
| P10-Grid balancing capacity | High | High | High | Low | Medium | Low | Low | Low |
| P11-Requirements for electricity grid infrastructure | Easy | Easy | Easy | Easy | Easy | Easy | Challenging | Challenging |
| P12-Requirements for skilled staff for operation and maintenance and for special spare parts | Low | Low | High | Low | Low | Low | Low | Low |
| P13-Possibility for camouflage and sheltering | High | High | Medium | High | High | High | Medium | Medium |
| P14-Risk associated with fuel supply | High risk | High risk | Medium risk | Low risk | Low risk | Low risk | Low risk | Low risk |
| P15-Restoration time | In between | In between | Lengthy and complicated | Quick and easy | Quick and easy | Quick and easy | Quick and easy | In between |

| Criteria evaluation | 3.a. Wind onshore farms (>20 MW) | 3.a. Used wind onshore farms (>20 MW) | 3.a. Wind onshore cluster (4.2-20 MW) | 3.c. Wind household turbines (<100 kW) | 4. Coal retrofitting | 5.a. Bat, Li-ion utility scale | 5.b. Bat, Li-ion community scale |
|---|---|---|---|---|---|---|---|
| P1-Electricity production at wintertime | 50% | 50% | 50% | 50% | >75% | >75% | >75% |
| P2-Levelized Cost of Electricity (LCOE) short lifetime, winter production [€/MWh] | 785 | 553 | 901 | 2 628 | 609 | 2 967 | 2 549 |
| P3-Levelized Cost of Electricity (LCOE) over lifetime [€/MWh] | 38 | 35 | 42 | 167 | 146 | 155 | 261 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| P4-Distributed generation | Medium | Medium | Good | Good | Poor | Medium | Good |
| P5-Regulation requirement in the project development process | Lengthy | Lengthy | Lengthy | Quick and easy | In between | In between | In between |
| P6-Delivery time and availability of components and materials | In between | Quick and easy | In between | Quick and easy | In between | In between | In between |
| P7-Requirements for logistics and transportation infrastructure | High | High | High | Low | Medium | Low | Low |
| P8-Technical installation time (after clearance) | Medium-term | Medium-term | Medium-term | Quick and easy | Lengthy and complicated | Quick and easy | Quick and easy |
| P9-Requirements for skilled staff in construction phase | Medium | Medium | Medium | Medium | Medium | Low | Low |
| P10-Grid balancing capacity | Medium | Medium | Medium | Medium | Medium | High | High |
| P11-Requirements for electricity grid infrastructure | Moderate | Moderate | Moderate | Easy | Moderate | Easy | Easy |
| P12-Requirements for skilled staff for operation and maintenance and for special spare parts | Medium | Medium | Medium | Low | Low | Low | Low |
| P13-Possibility for camouflage and sheltering | Medium | Medium | Medium | High | Low | Medium | Medium |
| P14-Risk associated with fuel supply | Low risk | Low risk | Low risk | Low risk | Medium risk | Medium risk | Medium risk |
| P15-Restoration time | In between | In between | In between | Quick and easy | In between | Quick and easy | Quick and easy |

| Criteria evaluation | 7.a. Wood pellets, CHP Medium | 7.b. Wood pellets, CHP Small | 7.c. Wood Chips, CHP Medium | 7.d. Wood Chips, CHP Small | 7.e. Straw, CHP Medium | 7.f. Straw, CHP Small |
|---|---|---|---|---|---|---|
| P1-Electricity production at wintertime | >75% | >75% | >75% | >75% | >75% | >75% |
| P2-Levelized Cost of Electricity (LCOE) short lifetime, winter production [€/MWh] | 1 087 | 1 273 | 1 256 | 1 304 | 1 250 | 1 368 |

| | | | | | | |
|---|---|---|---|---|---|---|
| P3-Levelized Cost of Electricity (LCOE) over lifetime [€/MWh] | 141 | 186 | 142 | 175 | 126 | 168 |
| P4-Distributed generation | Medium | Good | Medium | Good | Medium | Good |
| P5-Regulation requirement in the project development process | In between | In between | In between | In between | In between | In between |
| P6-Delivery time and availability of components and materials | In between | In between | In between | In between | In between | In between |
| P7-Requirements for logistics and transportation infrastructure | Low | Low | Low | Low | Low | Low |
| P8-Technical installation time (after clearance) | Lengthy and complicated | Medium-term | Lengthy and complicated | Medium-term | Lengthy and complicated | Medium-term |
| P9-Requirements for skilled staff in construction phase | Medium | Medium | Medium | Medium | Medium | Medium |
| P10-Grid balancing capacity | Medium | Medium | Medium | Medium | Medium | Medium |
| P11-Requirements for electricity grid infrastructure | Easy | Easy | Easy | Easy | Easy | Easy |
| P12-Requirements for skilled staff for operation and maintenance and for special spare parts | Low | Low | Low | Low | Low | Low |
| P13-Possibility for camouflage and sheltering | Medium | Medium | Medium | Medium | Medium | Medium |
| P14-Risk associated with fuel supply | Low risk | Low risk | Low risk | Low risk | Low risk | Low risk |
| P15-Restoration time | In between | In between | In between | In between | In between | In between |

| Criteria evaluation | 8.a. Hydro, RoR, small | 8.b. Hydro, RoR, micro | 8.c. Retrf Hydro power, dams incl. PHS |
|---|---|---|---|
| P1-Electricity production at wintertime | 40% | 40% | 70% |
| P2-Levelized Cost of Electricity (LCOE) short lifetime, winter production [€/MWh] | 1790 | 1503 | n.a. |

| | | | |
|---|---|---|---|
| P3-Levelized Cost of Electricity (LCOE) over lifetime [€/MWh] | 54 | 47 | n.a. |
| P4-Distributed generation | Good | Good | Poor |
| P5-Regulation requirement in the project development process | Lengthy | Lengthy | Quick and easy |
| P6-Delivery time and availability of components and materials | In between | In between | In between |
| P7-Requirements for logistics and transportation infrastructure | Low | Low | Medium |
| P8-Technical installation time (after clearance) | Lengthy and complicated | Lengthy and complicated | Medium-term |
| P9-Requirements for skilled staff in construction phase | Medium | Medium | Medium |
| P10-Grid balancing capacity | High | Low | High |
| P11-Requirements for electricity grid infrastructure | Easy | Easy | Easy |
| P12-Requirements for skilled staff for operation and maintenance and for special spare parts | Low | Low | Low |
| P13-Possibility for camouflage and sheltering | Medium | Medium | Low |
| P14-Risk associated with fuel supply | Low risk | Low risk | Low risk |
| P15-Restoration time | In between | In between | In between |

## 3.2. Initiatives that could or have improved the criteria performance

### 3.2.1. RE zone mapping (REZOMA)

Ensuring implementation speed is a key challenge for many technologies in the Urgent Technology Catalogue, including onshore wind power, which on other parameters appear very attractive. To pave the road for quicker approval decisions at the local level - and potentially provide a framework for fast-tracking renewable energy projects at the government or oblast level - the Danish-Ukrainian Energy Cooperation Programme has initiated two projects concerning renewable energy zone mapping (REZOMA).

The first project focuses on identifying suitable sites for large wind farms in Kirovohrad, Chernihiv, and Ternopil oblasts. The second project involves a country-wide assessment of the best sites for solar and wind projects, taking into consideration the available renewable energy resource, access to electricity infrastructure, and planning constraints, including environmental criteria and land-use and spatial criteria.

These renewable energy zone-mapping projects could also be instrumental in supporting Ukraine's compliance with the requirements of the Renewable Energy Directive (RED) EU 2023/2413 of 18 October 2023. According to Articles 15b and 15c, Member States are obligated to identify suitable areas for renewable energy and designate Renewables Acceleration Areas with streamlined permitting. These measures aim to speed up project approvals, reduce administrative barriers, and support the EU's renewable energy and climate targets. Even though Ukraine is not a member of the EU, Ukraine has committed to adopting parts of EU energy legislation, including renewable energy directives. By identifying and prioritizing optimal locations for renewable energy development, the renewable energy zone mapping projects can help streamline permitting processes, reduce administrative barriers, and ensure that renewable energy projects are implemented in a manner that aligns with environmental and spatial planning considerations.

### 3.2.2. Streamlining Land Zoning for Accelerated Energy Development in Ukraine

In February 2024, the new law "On Amendments to Certain Legislative Acts of Ukraine to Attract Investments for the Purpose of Rapid Reconstruction of Ukraine" was introduced to streamline the process of changing land zoning, addressing the urgent need to accelerate the development of new energy projects. This legislation eliminates the requirement to develop separate town planning and land management documentation that previously could take 1-3 years. According to the Ukraine Recovery Fund, this reform enables all necessary permits to be obtained in less than 1.5 months, significantly expediting the build-out of energy infrastructure, including renewable energy facilities.

### 3.2.3. Positive list for power producing, demand, and storage facilities

Implementation speed is one of the key parameters for a smooth transition to a more renewable based energy system. A whitelist named as a "positive list" in Denmark is an innovative tool that simplifies the compliance validation process of connecting production, demand, and storage facilities to the electricity grid system.

A positive list contains pre-screened units with unit/equipment certificates (e.g. wind turbines, gas generators, non-synchronous hydro generators), and/or pre-screened plant components (e.g. certified PV inverters, power plant controller, software applications) that meet the fundamental technical requirements according to the EU RfG Network Code (EU regulation 2016/631) and the EU DC Network Code (EU regulation 2016/1388). As the EU connection network codes are concerned about grid system stability, the requirements are organized in categories A, B, C and D. The positive list is primarily interesting for developers/owners of small-scale units in the category A and B, but applying many small-scale units in an aggregated manner to form a power plant, the positive list can also be interesting as compliance verification of the individual power module can be provided with an equipment certificate and shorten the compliance verification process. In addition, the relevant grid system operator only needs to inspect the equipment certificate once and thereby reduce time for the compliance verification process.

By using a positive list, grid system operators and facility owners can save time and resources in the compliance approval process, while ensuring the technical compatibility and securing grid stability.

The administrative responsibility of a positive list with time limited pre-screened unit/equipment certificates and plant components is recommend being hosted on Ministerial or eventually on interest organization level as implemented in Denmark. For more details see Appendix C, subsection 11.1.

## 3.3. Methodology changes between catalogue version 1 and version 2

Several significant changes have been made in the assessment of technologies in the catalogue between version 1 (2024) and version 2 (2025):

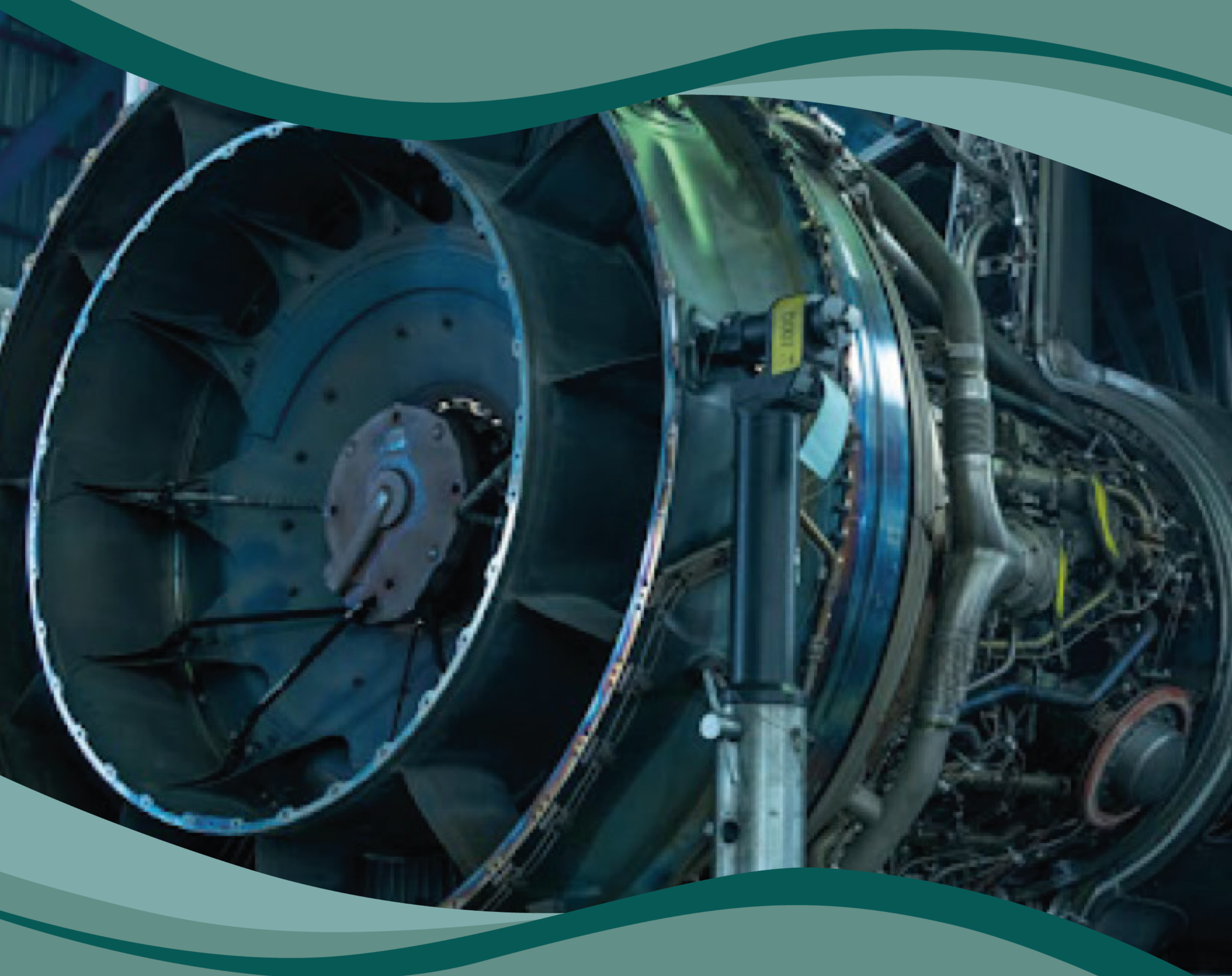
- **Expanded interview base:** More interviews have been conducted with new stakeholders, along with follow-up interviews with previous participants. This has led to adjustments in the evaluation of certain technologies as new perspectives and updated experiences have been incorporated.
- **Introduction of a new evaluation parameter:** A new parameter, P15-Restoration time, has been added to provide a more detailed assessment of a technology's ability to recover quickly after breakdowns or interruptions. The parameter is included in the resilience criteria.
- **Increased focus on labour requirements:** Stakeholder interviews have highlighted growing challenges in recruiting labour, both general and specialized, as many workers have been mobilized for the war. As a result, labour requirements have been assigned greater weight in the assessment of technology construction and maintenance in version 2 of the catalogue.
- **More nuanced evaluation of distributed generation:** A more detailed assessment of distributed generation technologies has been introduced, now including whether the technology can be placed close to the consumer and whether it is modularly constructed. This provides a more realistic view of the technology's flexibility and implementation potential.
- **Increased risk associated with fuel supply for gas:** Ukraine decided not to renew the five-year gas transit deal with Russia, which expired at the end of 2024. This decision effectively stopped the flow of Russian gas through Ukrainian pipelines starting January 1, 2025. With the halt in Russian gas transit, the risk associated with gas supply is considered substantially higher (see Appendix 11.3 Risk of Gas Supply Cuts in Ukraine).

## 3.4. The structure of the technology chapters

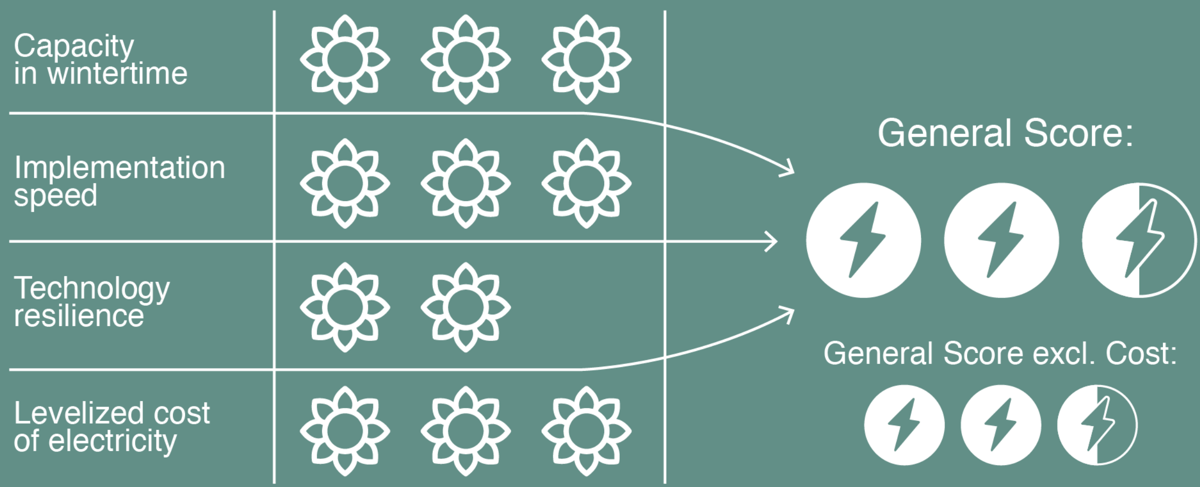
Each technology chapter begins with an overview of the technology group, highlighting the key findings for the respective segments. This is followed by a comprehensive evaluation of each sub-technology that includes:

1. A concise description of the technology, including its potential relevance to Ukraine where applicable.
2. An assessment based on the four defined criteria.
3. An evaluation of the fifteen defined parameters.
4. A corresponding data sheet provided in Excel format, located in Appendix F.

Due to shared similarities between some of the technologies, the order of the evaluation differs from one technology to another and some of the evaluation points are presented together for clusters of sub-technologies.



# GAZ POWER PLANTS



# 4. Evaluation of technologies

In this section, the technologies are briefly described technically and evaluated regarding criteria and parameters.

## 4.1. Gas power plants

The rating on the front page shows the score for the technology achieving the highest general score among the sub technologies evaluated in the chapter. The more icons, the better performance[8]. For gas technologies, it is the gas engines fueled by natural gas that achieve the best score. The scores for all sub-technologies are shown in Table 7.

*Table 7: Gas power plants – Overall criteria evaluation matrix*

| Criteria evaluation | 1.a. Gas turb. simple cycle, NG | 1.b. Gas engines, NG | 1.c. Gas engines, biogas |
|---|---|---|---|
| Winter impact | WWW | WWW | WWW |
| Implementing speed | QQ | QQQ | Q |
| Resilience | R | RR | R |
| Cost (LCOE, wintertime 2 years lifetime) | CCC | CCC | CCC |
| General score (1-3) | 2.4 | 2.5 | 2.2 |
| General scores (excl. cost) (1-3) | 2.2 | 2.5 | 2.0 |

This chapter covers three types of gas power plants:

- Gas turbines, simple cycle, fuelled by natural gas
- Gas engine, fuelled by natural gas
- Gas engine, fuelled by biogas (not upgraded) that is exclusively supplied with fuel from the associated greenfield project biogas plant

Both gas turbines and gas engines can be manufactured across a broad spectrum of sizes, spanning from 20-25 kilowatts to multiple megawatts. Specifically for this project, the focus is on an open-cycle gas turbine with a capacity ranging from 5 to 40 MW and a gas engine with a capacity ranging from 1 to 10 MW. The selection of these technologies is primarily intended to underscore distinctions in gas power plants of varying sizes, rather than emphasizing the choice between turbine and engine technologies.

8 See detailed explanation in Table 2: Overview of the parameters contributing to each criterion, along with the corresponding ratings. The number of icons represents the quality of the rating, with more icons indicating a better rating.

## 4.1.1. Gas turbines, simple cycle

### 4.1.1.1. Brief technology description

The main components of a simple-cycle (or open cycle) gas turbine power unit are a gas turbine, a gear (when needed), a compressor, a combustion chamber, and a generator; see Figure 7.

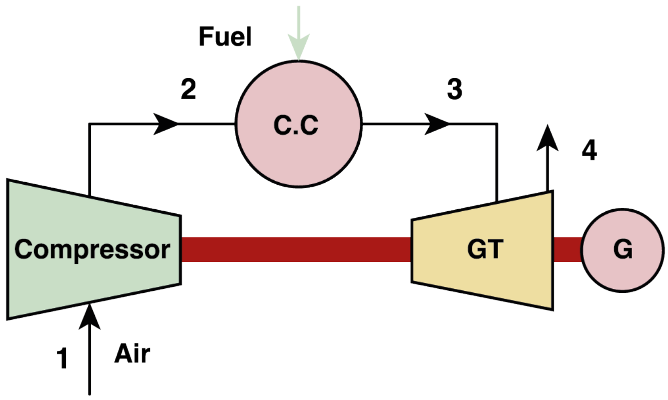



*Figure 7: Process diagram of a SCGT*

Gas turbines can be equipped with compressor intercoolers where the compressed air is cooled to reduce the power needed for compression. The use of integrated recuperators (preheating of the combustion air) to increase efficiency can also be made by using air/air heat exchangers – at the expense of an increased exhaust pressure loss. Gas turbine plants can have direct steam injections in the burner to increase power output through expansion in the turbine section (Cheng Cycle). Small (radial) gas turbines below 100 kW are now on the market, the so-called micro-turbines. These are often equipped with preheating of combustion air based on heat from gas turbine exhaust (integrated recuperator) to achieve reasonable electrical efficiency (25-30%).

### 4.1.1.2. Criteria evaluation

*Table 8: Gas turbines, simple cycle – criteria evaluation matrix*

| Criteria evaluation | 1.a. Gas turb. simple cycle, NG |
|---|---|
| Winter impact | WWW |
| Implementing speed | QQ |
| Resilience | R |
| Cost (LCOE, wintertime 2 years lifetime) | CCC |
| General score (1-3) | 2.4 |
| General scores (excl. cost) (1-3) | 2.2 |

**Winter impact (production at wintertime)**

Gas turbine can significantly contribute to the Ukrainian power system in winter. Gas engines are dispatchable and can realistically operate at a high capacity for a longer period, approaching 90-100% of their max. capacity, if needed. Thus, the gas turbine can achieve more than 75% of its maximum technical capacity during the winter half-year. With it, the gas engine is assessed to score good on winter impact.

**Implementing speed**

The implementation time is very dependent on the size of the project and the choice of technology. Delivery time for the technology itself is deemed to be around 1 year but could potentially be lower if used equipment is applied, whereas the installation would typically take half a year for a project in the size of 10-40 MW. Including the time for planning and regulation approvals the total time for project delivery could be around 1.8 years.

**Resilience**

The resilience of gas turbines can be attributed to serval key factors. Firstly, their modest capacity enables the dispersion of small gas turbines over a wide geographic area. This dispersion reduces vulnerability to potential air strikes from artillery, missiles, or drones. Secondly, the relatively small footprint of gas turbines allows for installation within bunkers that can be effectively camouflaged to enhance their security. Thirdly, there are potential disruptions to the gas supply. It is assumed that since the gas transit agreement with Russia is now abandoned, the likelihood that Russia may begin targeting Ukraine's gas pipelines and storage facilities is increasing[9]. Thus, the risk is assumed to be high.

**Generation costs (LCOE), short term and over the lifetime**

Due to their low upfront costs[10] and great potential for generation during winters, gas turbines demonstrate the lowest generation cost of all technologies over the course of two winters. On the other hand, the levelized cost over their entire lifetime is about two to three times higher than the costs of wind and solar power.

#### 4.1.1.3. Data sheet

In Appendix F.

### 4.1.2. Gas engine

The section covers.

- Gas engine, fuelled by natural gas.
- Gas engine, fuelled by non-upgraded biogas, is exclusively supplied with fuel from the associated greenfield project biogas plan.

There is no difference in the gas engine technology, the efficiency is slightly lower when fuelled by non-upgraded biogas. The biogas plant technology is described in the chapter Biogas.

#### 4.1.2.1. Brief technology description

9 In fact, there are indications that since end of 2024, Russia has increasingly struck against Ukraine's gas infrastructure. For example, on February 1, 2025, a Russian air attack comprising six missiles and 17 Shahed drones targeted gas infrastructure and other facilities (Reuters, 2025).

10 The investment cost is low compared to the other technologies included in this catalogue.

The evaluation includes a gas engine fuelled by natural gas and by non-upgraded biogas.

A gas engine for co-generation of heat and power drives an electricity generator for power production. Electrical efficiency up to 45-48% can be achieved. The engine cooling water (engine cooling, lube oil and turbocharger intercooling) and the hot exhaust gas can be used for heat generation, e.g., for district heating or low-pressure steam. Typical capacity of a gas engine ranges from 5 kWe to 10 MWe.

Two combustion concepts are available for spark ignition engines: lean-burn and stoichiometric combustion engines. Another ignition technology is used in dual-fuel engines. A dual-fuel engine (diesel-gas) with pilot oil injection is a gas engine that – instead of spark plugs – uses a small amount of light oil (1-6%) to ignite the air-gas mix by compression (as in a diesel engine). Dual fuel engines can often operate on diesel oil alone as well as on gas with pilot oil for ignition. Figure 8 shows a gas engine cogeneration unit with heat recovery boilers and an absorption steam driven heat pump to obtain high heat production and highest possible overall efficiency.

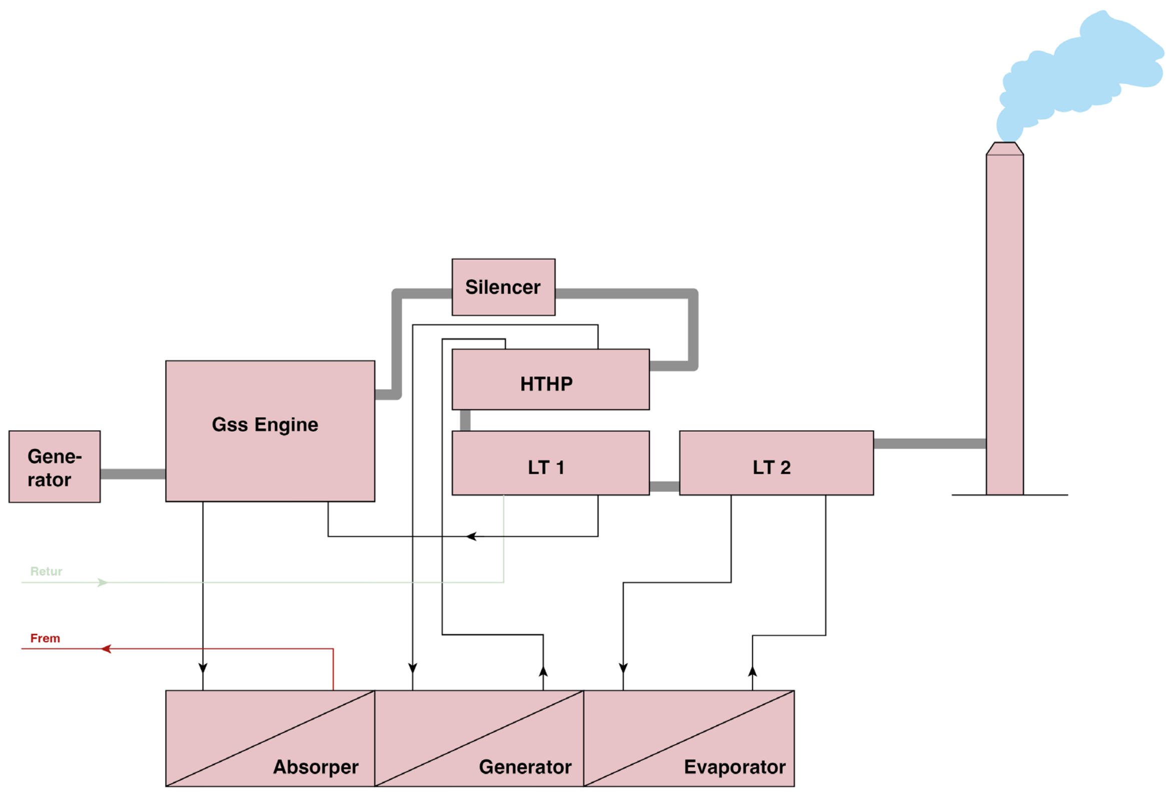



*Figure 8: Gas engine cogeneration unit*

## 4.1.2.2. Criteria evaluation

The evaluation is conducted for gas engine fuelled by natural gas and by biogas. For the biogas version it is assumed that a new biogas plant should be installed, and that the engine is fuelled directly and solely from that biogas plant. However, the cost of the biogas plant is not included in the LCOE calculations, but in all the other parameter assessments.

*Table 9: Gas engines – criteria evaluation matrix*

| Criteria evaluation | 1.b. Gas engines, NG | 1.c. Gas engines, biogas |
|---|---|---|
| Winter impact | WWW | WWW |
| Implementing speed | QQQ | Q |
| Resilience | RR | R |
| Cost (LCOE, wintertime 2 years lifetime) | CCC | CCC |
| General score (1-3) | 2.5 | 2.2 |
| General scores (excl. cost) (1-3) | 2.5 | 2.0 |

**Winter impact (production at wintertime)**

Gas engines can significantly contribute to the Ukrainian power system in winter. Gas engines are dispatchable and can realistically operate at a high capacity for a longer period, approaching 90-100% of their max. capacity, if needed. Thus, the gas engine can achieve more than 75% of its maximum technical capacity during the winter half-year. With it, the gas engine is assessed to score **good** on winter impact.

**Implementing speed**

The implementation timeline hinges significantly on the project's size. Technology delivery is estimated at little less than one year, potentially shorter with the use of pre-owned equipment. Installation durations vary, taking a few weeks for a smaller 1 MW project and up to half a year for a larger 10 MW project requiring customized installation. Accounting for planning and regulatory approvals, the overall project delivery time could be estimated to be between one and one and a half years.

**Resilience**

The resilience of gas engines can, as described in the section for gas turbines, be attributed to serval key factors. Firstly, their modest capacity facilitates the dispersion of gas engines across a broad geographic area, reducing vulnerability to potential air strikes from artillery, missiles, or drones. Secondly, the very compact footprint of gas engines allows for bunker installation, enhancing security through effective camouflage. Thirdly, there are potential disruptions to the gas supply. It is assumed that since the gas transit agreement with Russia is now abandoned, the likelihood that Russia may begin targeting Ukraine's gas pipelines and storage facilities is increasing[11]. Thus, the risk is assumed to be high.

The gas engines using natural gas are assessed to perform better than gas turbines on the first two key factors, while the risk of disruption to the gas supply is assessed to be the same. Conversely, for the gas engine solely supplied by a greenfield biogas plant project, the first key factor is set to be at the same level or worse than for gas turbines, as the vulnerability of the biogas plant is included in the assessment. However, it is assumed that the risk of disruption to the fuel supply is lower for the biogas engine than for natural gas plants.

11 In fact, there are indications that since end of 2024, Russia has increasingly struck against Ukraine's gas infrastructure. For example, on February 1, 2025, a Russian air attack comprising six missiles and 17 Shahed drones targeted gas infrastructure and other facilities (Reuters, 2025).

**Generation costs (LCOE), short term and over the lifetime**

Because of their low initial investment and considerable winter generation potential, gas engines exhibit the lowest generation cost among all technologies over two winters. However, the levelized cost over their entire lifespan is approximately two to four times higher than that of utility scale wind and solar power.

## 4.1.3. Gas power parameter evaluation

This section covers both gas turbines and gas engines since their characteristics, challenges, and opportunities are largely the same. Engines using biogas as fuel are also discussed.

*Table 10: Gas Power – parameters evaluation matrix. The LCOE unit is [€/MWh]*

| Criteria evaluation | 1.a. Gas turb. simple cycle, NG | 1.b. Gas engines, NG | 1.c. Gas engines, biogas |
|---|---|---|---|
| P1-Electricity production at wintertime | >75% | >75% | >75% |
| P2-Levelized Cost of Electricity (LCOE) short lifetime, winter production [€/MWh] | 356 | 405 | 479 |
| P3-Levelized Cost of Electricity (LCOE) over lifetime [€/MWh] | 169 | 142 | 220 |
| P4-Distributed generation | Good | Good | Good |
| P5-Regulation requirement in the project development process | In between | Quick and easy | Lengthy |
| P6-Delivery time and availability of components and materials | In between | In between | Lengthy and complicated |
| P7-Requirements for logistics and transportation infrastructure | Low | Low | Low |
| P8-Technical installation time (after clearance) | Medium-term | Quick and easy | Lengthy and complicated |
| P9-Requirements for skilled staff in construction phase | Low | Low | Medium |
| P10-Grid balancing capacity | High | High | High |
| P11-Requirements for electricity grid infrastructure | Easy | Easy | Easy |
| P12-Requirements for skilled staff for operation and maintenance and for special spare parts | Low | Low | High |
| P13-Possibility for camouflage and sheltering | High | High | Medium |
| P14-Risk associated with fuel supply | High risk | High risk | Medium risk |
| P15-Restoration time | In between | In between | Lengthy and complicated |

**P1: Electricity production in wintertime (W)**

Gas turbines and gas engines rely on gas as fuel. If there is fuel available, they can operate at their full capacity any hour of the day, except for the planned and forced outages. Depending on the specific gas-turbine or engines, there are different requirements for when the plant should be maintained, meaning that there will be some weeks of the year where it is planned that the gas turbine or engine will be out of operation. Typically, the maintenance is planned to be done during the summer, when the need for the plant is lower. Forced outages can happen for multiple reasons. Therefore, it is estimated that the gas power plant can operate at full load more than 95% of the time during winter that corresponds to 4150 FLH hours. 4 150 FLH corresponds to a little more than the annual FLH of an onshore wind turbine, located in the Ukrainian region with the best wind profiles and above twice the annualized FLH of a PV plant located in the Ukrainian region with the best solar profile. In summary, gas turbines and engines may be considered a great power source during the wintertime.

**P2/3 LCOE expected production**

It is expected that the need for electricity delivered by gas engine or turbine is considerably higher during the winter. Because the power demand is higher, partly due to that the heat demand is considerably higher. Furthermore, a larger share of the electricity is assumed to be generated through not variable technologies and technologies with a lover variable operation cost like photovoltaics, wind, hydro, and nuclear.

Due to these reasons, although the gas technologies could operate at full capacity 8 100 hours per year, it is assumed that a gas turbine and engine will operate to what equates to full capacity for 5 000 hours during a year.

Most of the production is likely to happen during the winter period, therefore it is assumed that 75% of the FLH will occur during the wintertime, which means that gas engine and turbine is assumed to operate 3 750 full load hours during the wintertime. This corresponds to approximately 85% of max capacity.

**P2: Levelized Cost of Electricity (LCOE) short lifetime, winter production (C)**

In the emergency scenario, where the technology is only utilized for two winter periods, the LCOE of the natural gas engine and turbine are the lowest of all technologies assessed. For a gas turbine with a simple cycle, the LCOE is expected to be €356 per MWh, compared to about €405 per MWh for the gas engine and €479 per MWh for the engine supplied with non-upgraded biogas.

Natural gas engines and turbines stand out for the short time because 80% of their lifetime expenditure is caused by fuel consumption, whereas the investment cost including financing is relatively low. When only assessing the cost over a reduced operational period of 2 years, the amount of fuel consumed and thus the fuel costs are proportionately reduced, the same is true for a large share of the and so is the cost for operation and maintenance (O&M).

Gas engines fuelled by non-upgraded biogas would have slightly higher investment cost than that of the natural gas engine, to make it possible to use biogas that also contain a large portion of CO2 as a fuel in an efficient way. Furthermore, fuel is a little more costly. This drives the LCOE of the biogas engine to be significantly higher than that of the natural gas engine.

**P3: Levelized Cost of Electricity (LCOE) over lifetime (C)**

For a gas turbine with a simple cycle, the LCOE over lifetime is expected to be approx. €169 per MWh. For the gas engine the LCOE is expected to be about €142 per MWh. This is two-three times higher than utility scale solar and wind power but approximately the same as for biomass technologies included and the small-scale wind and solar technologies. The LCOE of gas engines fuelled by biogas is €220 per MWh that is the highest cost of all the assessed technologies. Fuel costs make up most costs and therefore obviously, the generation cost from gas technologies are highly sensitive to the gas price trends. In the projected LCOE the long-term gas price is set to €81 per MWh (HHV), assuming that LNG sets the price in the European market.

**P4: Distributed generation (R)**

Typical gas turbines have a generation capacity that ranges from 1-40 MW, and the typical gas engines have a generation capacity of 1-10 MW. This means that both gas engines and turbines offer a scalable choice of decentralized energy production. As it might be more typical for a gas turbine to have a capacity above 5 MW, the gas turbines can generally be considered to have a medium distributed generation capacity. As gas engines have a power generation capacity of 1-5 MW, the gas engine can be easy to distribute. Given the current situation in Ukraine, there are several compelling reasons to favour distributed installations. These installations, located near demand centres, offer the advantage of reducing dependence on the transmission grid, thereby mitigating the risks associated with potential power production capacity loss. Moreover, local power generation at the end-user's site diminishes the necessity for extensive electricity transmission, consequently bolstering energy security.

Additionally, the dispersion of gas turbines and gas engines across a broad geographic area renders them less susceptible to potential air strikes from artillery, missiles, or drones, further enhancing their resilience.

**P5: Regulation requirement in the project development process (Q)**

For the natural gas engine, the regulation requirement in the project development process is considered to be quick and easy. This is due to the fact that this technology comes in modular builds that are well known and pre-certified for operation. Furthermore, they do not require a lot of space that makes the planning process easier, as the building in which the technologies will be placed has a smaller impact on the local environment. This means that the process of carrying out an environmental impact assessment report is assumed to be relatively short. It's expected that the approval time will take around 8 weeks.

For the gas turbine, the approval process is expected to take around 20 weeks that lands the regulatory approval process to lie in the medium category. This is due to the fact that for gas turbines, there can be some tailor-made setups that need to be approved.

For the non-upgraded biogas engine, the approval process is expected to take around 52 weeks, as the biogas plant also has to be approved. This can take some time, as there are multiple factors that need to be accounted for.

**P6: Delivery time / availability of components and materials (Q)**

The delivery time for natural gas engines and turbines is expected to be approximately 1 year if they are ordered today. The reason why it takes so long for the delivery is the fact that the manufacturers do not build an inventory of natural gas engines and turbines, they build the units after they are ordered. This is typically due to different requirements from the end user, which means that even though the gas engines and turbines are built as a modular unit; there can be a varying degree of capacity size, and the manufacturers do not want to build a large inventory of different units, as the investment cost is quite high and there is no guarantee that the units will be purchased.

This means that when a gas engine or turbine is ordered, the manufacturer starts to order the components, such as engine blocks, cylinder heads, pistons, crankshafts, etc. Some of these components the manufacturer might craft themselves. But the process of receiving all these components takes time, as there currently is a constriction on the raw materials and components, which means that there will be a wait time before the components and needed materials are received. This delays the beginning of the assembly process, on top of the assembly process also requiring some time. Furthermore, through the interviews, it became apparent that there are some constraints on the availability of transformers that with some exceptions are needed to couple the gas engine and turbine to the grid. The transformers are expected to be deliverable within 1 year, which means that even if the gas engine or turbine is assembled ahead of time, they might not be able to be coupled to the grid because of a missing transformer. Through the interviews, some manufacturers of gas engines expressed that a 0.5-1 MW gas engine might be connectable to the grid without any transformer.

Compared to some of the other technologies, 1 year is considered to be **in between** in regards of delivery time. For the non-upgraded biogas engine, this delivery is expected to be **longer**, as the entire gasification plant has to be constructed as well.

**P7: Requirements for logistics and transportation infrastructure (Q)**

This unit and the components needed for the construction typically require transport by equipment of the size of a semitruck that requires a road. This means that the gas engine and turbine have a low requirement for logistics and transportation infrastructure, as roads and semitrucks are easily available. Furthermore, components for the construction of a gasification plant are also typically transported via semitrucks.

**P8: Technical installation time (min time after clearance) (Q)**

The installation time depends on the project size. For larger gas turbines and gas engines (2-5 MW or above), after the gas engine and turbine have been delivered to the target location, it will take around 26 weeks for the gas turbine and 8 weeks for the gas engine to do all the technical installations, even though the turbine or engine comes as a module. This is because the site needs to be prepared for construction and roads to the plant need to be built, utilities connections and other necessary infrastructure. The foundation for the engines or turbines needs to be constructed, so do the associated structures. Then the engines or turbines can be installed together with ancillary equipment. After this is done, the functionality, safety, and production can be tested. All these processes are expected to take time but can be lowered with some preparation, but even if this is done, it is expected to take 26 and 8 weeks respectively in general as it cannot be expected that everything will operate smoothly. Contractors might be delayed or there might be some scheduling issues that will cause some down time during the construction.

When compared to the other technologies, the installation time is expected to be in the medium range for the gas turbines and short for the gas engines. The difference stems from the ancillary service for the gas turbine being more complex than that of the gas engine.

Smaller gas engines with a capacity of up to 1 MW (cascade systems with higher capacity are also possible) may be supplied in a container system allowing for a rapid installation within a few weeks.

For the biogas engine, the construction of the gasification plant is expected to be long and lengthy, taking around 78 weeks due to the size of the plant.

**P9: Requirements for skilled staff in construction phase (Q)**

During the construction phase, general labourers, heavy equipment operators, concrete workers, welders, plumbers, electricians, HVAC technicians, and safety specialist workers are required. These labourer types are easy to acquire for the construction phase, as they are readily available in Ukraine or can be sent from other countries, depending on company policies. If companies cannot send their employees to Ukraine to perform the construction due to security concerns, some companies can and will educate general labourers from Ukraine. During the interviews, it was established that the training for assembling a small gas engine or turbine plant might take some months that could take place during the assembly of the ordered gas engines or turbines, which is why the requirement for skilled staff is low during construction phase.

For the non-upgraded biogas engine, this requirement is set as **medium**, as there is the added extra element of the gasification plant.

**P10: Grid balancing capacity (R)**

If there is natural gas or biogas available, the natural gas engine, -turbine, and biogas engine, can produce electricity at any hour of the day and the startup is very quick. Therefore, the grid balancing capacity is considered to be **high** for all these technologies.

**P11: Requirements for electricity grid infrastructure (Q)**

Depending on the generation capacity of the gas engines or turbines, there will be different requirements for the electricity grid when coupling the gas engines and turbines to the power grid. As gas turbines can have a generation capacity above 10 MW, the requirements for connecting the gas turbines to the grid are higher than that of a gas engine. But the requirement for the coupling of the gas turbine to the grid is considered to fall in the lower end of easy, as they can be connected to almost any grid if the gas turbines are coupled via a transformer. As previously mentioned, the gas engines might not require a transformer if the generation capacity is below

1 MW and the gas engines can be connected to the grid almost anywhere, which is why the connection of a gas engine to the electricity grid is expected to be easy.

**P12: Requirements for skilled staff for operation and maintenance and for special spare parts (R)**

To keep a gas engine or turbine plant in operation, operations-, maintenance-, instrumentation-, electrical- and mechanical technicians are required. Depending on the plant size, these technicians might not be needed for full time employment but can be called in when there is a specific problem regarding their field of work. Depending on the plant size an operations technician can manage multiple small units from the same control room. Because each of these professions can be spread out on multiple plants, and they can quickly be educated while the order of gas turbines or engines is under way, the requirement for skilled labour is considered to be low in comparison to other technologies. Specifically for the biogas plant, the requirement of the staff is expected to be high.

**P13: Possibility for camouflage and sheltering (R)**

Gas turbines and engines have a small footprint, which means that they can easily be put into a bunker that can be camouflaged. Therefore, the possibility for camouflage and sheltering is rated to be of **high** potential. For the biogas plant, the potential falls within the **medium** category taking into account the biogas production plant.

**P14: Risk associated with fuel supply (R)**

It is expected that there is a **high** risk associated with the supply of natural gas to the turbines and engines. Since the gas transit agreement with Russia is now abandoned, the likelihood that Russia may begin targeting Ukraine's gas pipelines and storage facilities is increasing.

Most likely the gas transit agreement provided Russia with an incentive to avoid damaging infrastructure used for European gas deliveries. However, with the agreement now abandoned, this constraint has disappeared, increasing the likelihood that Russia may begin targeting Ukraine's gas pipelines and storage facilities. In fact, there are indications that since end of 2024, Russia has increasingly struck against Ukraine's gas infrastructure. For example, on February 1, 2025, a Russian air attack comprising six missiles and 17 Shahed drones targeted gas infrastructure and other facilities (Reuters, 2025).

Gas infrastructure, including pipelines, storage facilities, and processing plants, is vulnerable to air strikes. The extent of the vulnerability depends on several factors, including the type of infrastructure, its design, and the nature of the attack. While underground pipelines and storages are less exposed, above-ground infrastructure, such as compressor stations and the surface infrastructure of underground storages (e.g., injection and extraction facilities) remain vulnerable to air attacks that could disrupt distribution within Ukraine[12].

If the gas engines utilize biogas, the risk associated with the fuel supply is expected to be **medium**, since the biogas consumed is from own biogas facilities to which the engines are connected directly. The risk for attacks on the biogas production plant and internal pipelines is assessed to be **medium**. Furthermore, the biogas facilities are expected to use agricultural waste products, which there is an abundance of in Ukraine.

**P15: Restoration time (R)**

The expected restoration time of a damaged gas turbine or engine is expected to take around 20-40 weeks, which is the time that it would take to acquire new components, as well as implementing the repairs, it is expected that in general it will take half the time for construction of a green field plant. In comparison to the time for some of the other technologies, the restoration time lies **in between** other technologies.

12 Risk assessment partly based on assessment made by the Ukrainian thinktank Dixigroup, partly on the IEA 2024 report (see Appendix 11.3 Risk of Gas Supply Cuts in Ukraine).

For the biogas engine the restoration time is expected to take around 80 weeks as also the biogas production plant would have to be reconstructed, putting the gas engine fuelled by non-upgraded biogas in the **lengthy and complicated category.** Biogas plants typically contain large amounts of gas, meaning that a direct damaging strike could ignite the entire plant, damaging most of the plant.

## 4.2. Biogas plant

The biogas producing plant is only included as a technology that produces fuel to the gas engine, fueled by biogas. At the level as the power producing technologies, it is only included as fuel for the gas engine. Therefore, there is no criteria evaluated of biogas. And the evaluation therefore only contains the relevant parameters (excl. P10-Grid balancing capacity and P11-Requirement for electricity grid infrastructure). There is conducted no criteria evaluation, and the technology should be considered together with a gas power plant.

### 4.2.1. Brief technology description

Biogas, produced by anaerobic digestion, is a mixture of several gases. The most important part of biogas is methane but also CO2 makes up a considerable part. Biogas has a caloric value between 23.3 MJ/m3 and 35.9 MJ/m3, depending on the methane content. The volume of methane in biogas varies between 50% and 72% depending on the type of substrate and its digestible substances, such as carbohydrates, fats, and proteins. If the material consists of mainly carbohydrates, the methane production is low. However, if the fat content is high, the methane production is likewise high. For the operation of power generation or CHP units with biogas, a minimum concentration of methane of 40% to 45% is needed. The second main component of biogas is carbon dioxide. Its share in biogas reaches between 25% and 50% of volume. Other gases present in biogas are hydrogen sulphide, nitrogen, hydrogen, steam, and carbon monoxide. If the biogas is upgraded and CO2 is removed and stored, it can provide negative emissions or can be reacted with hydrogen to produce additional biomethane.

Anaerobic digestion (AD) is a complex microbiological process in the absence of oxygen used to convert the organic matter of a substrate into biogas. The population of bacteria that can produce methane cannot survive with the presence of oxygen. The microbiological process of AD is very sensitive to changes in environmental conditions like temperature, acidity, level of nutrients, etc. The temperature range that would give better cost-efficiency for operation of biogas power plants are around 35-38°C (mesophilic) or 55-58°C (thermophilic). Mesophilic gives hydraulic retention time (HRT) between 25 and 35 days and thermophilic – 15-25 days.

Examples of expected feedstocks of biogas production in Ukraine are manure, wastewater, Jatropha, Castor, Croton, and related seeds. Biogas production units could also be used for treatment of municipal solid waste. Some of the biomass potential can be converted to biogas.

Biogas from a biodigester is transported to the gas cleaning system to remove sulphur and moisture before entering the gas engine to produce electricity. The excess heat from power generation with internal combustion engines can be used for space heating, water heating, process steam covering industrial steam loads, product drying, or for nearly any other thermal energy need. The efficiency of a biogas power plant is about 35% if it is just used for electricity production. The efficiency can go up to 80% if the plant is operated as combined heat and power (CHP).

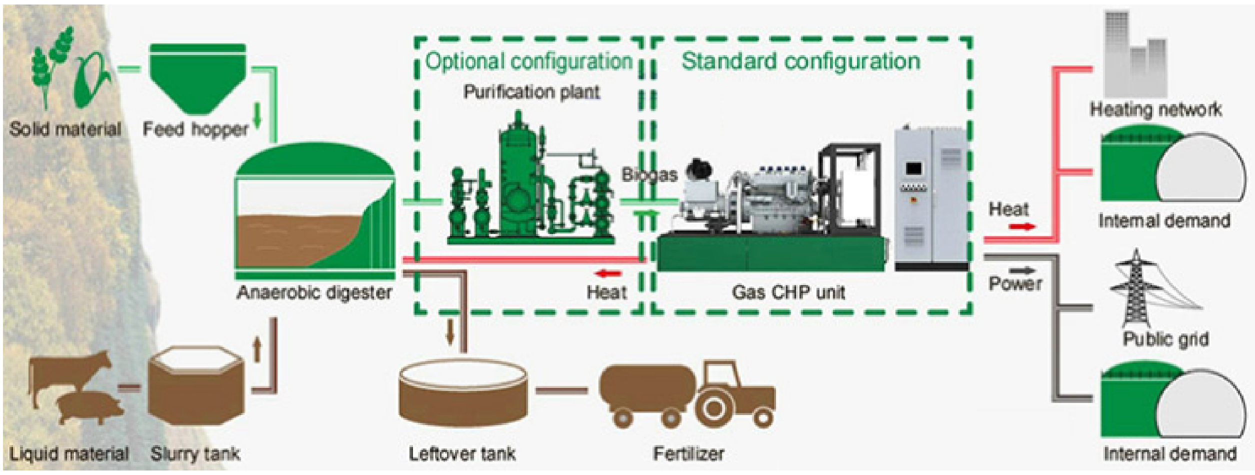



*Figure 9: Schematic diagram for a biogas CHP system*

## 4.2.2. Criteria evaluation biogas plant

No criteria evaluations are conducted. And the technology should be considered together with a gas power plant.

## 4.2.3. Parameter evaluation biogas

The overview of the parameter evaluation of the biogas plant has not been accomplished due to it not producing electricity.

**P1: Electricity production at wintertime (W)**

Biogas plants can produce gas independently of the season and operate at full capacity during the winter months.

**P2: Levelized Cost of Electricity (LCOE) short lifetime, winter production (C)**

The investment cost of a large-scale biogas plant (+5 MW) is relatively high, which means that the cost of producing biogas will be higher if the plant's operational lifetime is limited to only a few years. However, the cost is considered **medium** when compared to other technologies assessed in this catalogue that are more investment heavy.

**P3: Levelized Cost of Electricity (LCOE) over lifetime (C)**

The cost over the lifetime is average in comparison with other technologies assessed in this catalogue.

**P4: Distributed generation**

Biogas plants are categorized as **medium** for distributed operation because their typical capacities range between 5 MW and 20 MW. This size allows them to balance scalability and proximity to demand centres. While they are larger than small, modular technologies, biogas plants can still be strategically placed near agricultural or industrial waste sources, supporting local energy needs and reducing fuel transport costs.

**P5: Regulation requirement in the project development process (Q)**

Biogas plants receive a **good** rating in this category due to the generally quick and straightforward permitting and approval process. So far, no significant challenges have been identified that would extend the processing time beyond three months.

**P6: Delivery time / availability of components and materials (Q)**

Biogas plants receive a **medium** rating in this category due to delivery delays for critical components, particularly membrane technologies. Current market conditions show high demand for these units, resulting in waiting times ranging from six to nine months.

**P7: Requirements for logistics and transportation infrastructure (Q)**

Biogas plants receive a **medium** rating in this category due to their moderate dependency on transportation infrastructure. While some components of biogas plants, such as standard pipes, tanks, and smaller equipment, can be transported using regular trucks, critical parts like large digesters, storage tanks, and enrichment units often require special transport due to their size and weight.

**P8: Technical installation time (min time after clearance) (Q)**

According to interviews, the technical installation time for biogas plants in Ukraine is lengthy. The grid connection process alone can take up to 9 months, in addition to the construction period.

**P9: Requirements for skilled staff in construction phase (Q)**

Biogas plants should be rated **medium** in P9-Requirement for skilled staff in the construction phase.

Constructing a large-scale biogas plant is a complex process that requires specialized skills for proper assembly and operation. Ukrainian companies have developed strong expertise in this area, with 90% of biogas plants in Ukraine built by domestic firms. At least five companies within the Bioenergy Association of Ukraine are capable of constructing biogas or biomethane plants. These companies effectively source components globally, assemble them correctly, and ensure the plants operate efficiently, adequately supporting the local market.

**P10: Grid balancing capacity (/demands) (R)**

Not relevant.

**P11: Requirements for electricity grid infrastructure (R)**

Not relevant.

**P12: Requirements for skilled staff for operation and maintenance and for special spare parts (R)**

Biogas plants should be rated **high** in P12-Requirements for skilled staff for operation and maintenance and for special spare parts.

Operating and maintaining a biogas plant involves complex biological and technical processes that require highly skilled personnel. Continuous monitoring, process optimization, and handling of specialized equipment are critical to ensuring efficient and stable plant performance.

**P13: Possibility for camouflage and sheltering (R)**

Due to their large physical footprint, including digesters, storage tanks, and processing units, biogas plants are difficult to conceal or shelter effectively. The scale and visibility of the infrastructure make it challenging to integrate these facilities into the landscape or provide adequate protection from external threats.

**P14: Risk associated with fuel supply (R)**

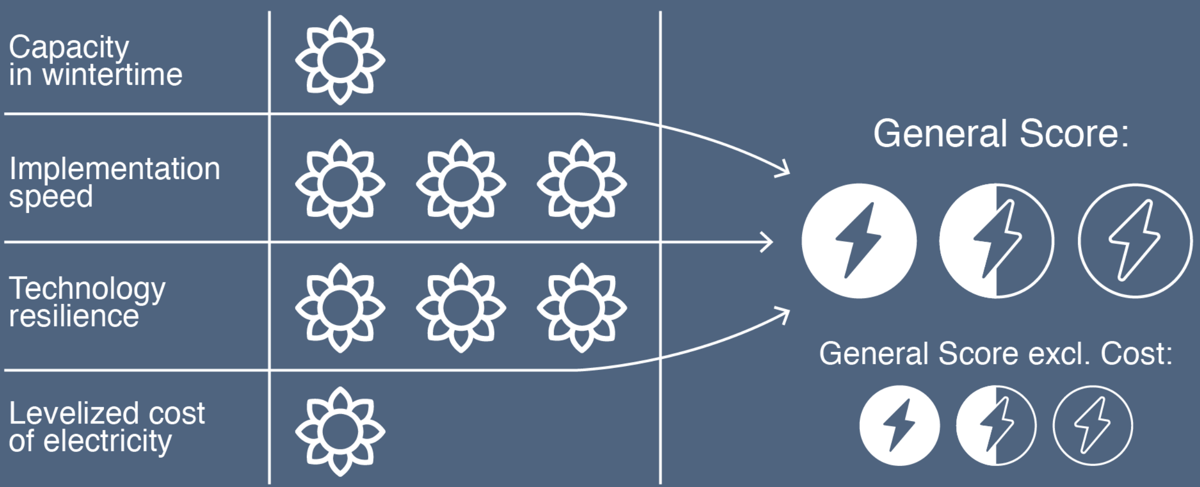
Biogas plants are rated **medium**.

Ukraine's large agricultural sector provides significant potential for biomass supply to biogas plants. However, the overall conditions for agricultural enterprises have deteriorated that may affect the consistent availability of feedstock. Despite this, the scale and diversity of Ukraine's agricultural sector help mitigate some of the risks, supporting a **medium** rating for this parameter.

**P15: Restoration time**

Restoration time for biogas plants is expected to be long, because of the long for building time for a biogas plant, depending on how large a share of the plant that has been destroyed. Biogas plants are rated **poor** for the restauration time parameter.

# PHOTOVOLTAICS



# 4.3. Photovoltaics

The rating on the front page shows the score for the technology achieving the highest general score among the sub technologies evaluated in the chapter. The more icons, the better performance[13]. For PV technologies, it is the rooftop PVs that achieve the best score. The scores for all sub-technologies are shown in Table 11.

*Table 11: Photovoltaics – Overall criteria evaluation matrix*

| Criteria evaluation | 2.a. PV residential rooftop | 2.b.5.b PV comm. & industrial – with battery | 2.b. PV comm. & industrial | 2.c. PV utility scale, ground mounted | 2.d. PV utility scale, floating |
|---|---|---|---|---|---|
| Winter impact | W | W | W | W | W |
| Implementing speed | QQQ | QQQ | QQQ | QQ | Q |
| Resilience | RRR | RRR | RRR | RRR | RRR |
| Cost (LCOE, wintertime 2 years lifetime) | C | C | C | CC | CC |
| General score (1-3) | 1.7 | 1.6 | 1.5 | 1.7 | 1.5 |
| General scores (excl. cost) (1-3) | 2.1 | 2.1 | 2.0 | 1.6 | 1.6 |

This chapter covers four different types of photovoltaic (PV) technologies:

- PV residential rooftop
- PV commercial, industrial, and public rooftop
- PV utility-scale
- Floating utility-scale PV

Firstly, a common brief technology description explaining the fundamental technical details that are general for PV. Hereafter, each technology is outlined in individual subchapters consisting of a brief technology description, criteria evaluation, and data sheet in Appendix F. The parameter evaluation for each technology, conversely, is conducted collectively, considering their shared similarities. Where possible a distinction between the technologies is conducted.

## Brief technology description

Solar energy converts energy from sunlight to electricity with the help of photovoltaic panels consisting of solar cells. A solar cell is a semiconductor component that generates electricity when exposed to solar irradiation. For practical reasons, several solar cells are typically interconnected and laminated to (or deposited on) a glass pane to obtain a mechanical ridged and weathering protected solar module.

In addition to PV modules, that are grid connected PV system i.e. deliver to AC systems also includes Balance of System (BOS) consisting of a mounting system, DC to AC inverter(s), cables, combiner boxes, optimizers, monitoring/surveillance equipment, and for larger PV power plants also transformer(s).

[13] See detailed explanation in Table 2: Overview of the parameters contributing to each criterion, along with the corresponding ratings. The number of icons represents the quality of the rating, with more icons indicating a better rating.

The photovoltaic (PV) modules are typically 1-2.5 $m^2$ in size and the best modules have a power capacity in the range of 220W/$m^2$ (and a technical efficiency around 22%). They are sold with a product warranty of typically ten to twelve years, a power warranty of minimum 25 years, and an expected lifetime of more than 30 years depending on the type of cells and encapsulation method. There are no large new PV projects installed currently within the reach of Russian military actions, because there is no warranty against military damage.

Solar PV plants can be installed at the distribution (roof top of single-family houses and on the roof top of or in relation to commercial or public building), at transmission level (utility-scale PV or floating PV), or used off-grid applications.

The production pattern of solar PV makes the technology attractive to combine with a short time battery storage, for example Lithium-ion batteries. While it would be clear cut to combine floating PV placed on dams of hydropower plants with pumped hydro storage. Anyways all types of solar PV could be combined with storage batteries, but in this report, there is only an example of combining the PV on commercial or public buildings with a Lithium-ion battery.

To calculate the generalized power generation from PV in different Ukrainian regions, a raster map covering all of Ukraine was used. The raster map originated from Global Solar Atlas[14]. The map is shown in Figure 10, it shows the expected annual PV generation in full load hours (FLH: MWh per MW installed capacity) in different regions of Ukraine. More details on the calculation methodology can be found in Appendix D.

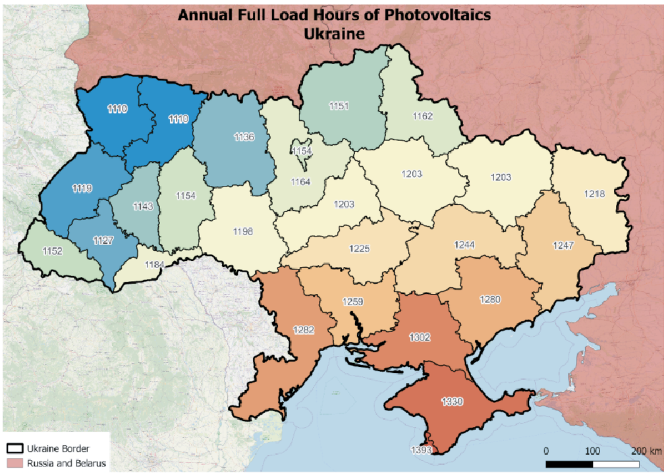



*Figure 10: Expected PV generation (MWh per MW installed capacity) in different regions of Ukraine. An annual production of 1 200 MWh/MW corresponds to a capacity factor of 14%. The maps are set up calculating the generalized power generation from photovoltaics in the different Ukrainian regions, Global Solar Atlas covering the period between 1994 and 2018 was used.*

## Overall assessment of the 4 criteria for PV

Solar PV technology offers significant generation potential and represents a scalable option for distributed energy generation that contributes positively to the resilience of the technology. In comparison to other renewable technologies, such as wind power and hydro, it boasts a relatively rapid development process, especially in the case of small-scale solar PV installations. However, when considering LCOE for the short lifetime and wintertime production PV exhibits one of the highest values, among all considered technologies. Regardless of providing one of the lowest LCOEs when calculated over the entire lifetime of energy production.

[14] https://globalsolaratlas.info/map

# 4.3.1. PV residential rooftop

## 4.3.1.1. Brief technology description

A PV residential rooftop refers to a solar PV system installed on the roof of a one family house. This system is designed to capture sunlight and convert it into electricity for on-site use or to feed back into the grid. It typically comprises solar panels, inverters, grid connection, and mounting structures, allowing homeowners to harness clean and sustainable energy from the sun to power their households. It is assumed that the total capacity of the PV modules in a residential system is up to 30 kW. The 30 kW limit is due to the current feed-in design. The installation is not limited to roofs, it could also be mounted on the ground nearby or on other constructions e.g., above the yard.

## 4.3.2.1. Criteria evaluation

*Table 12 PV residential rooftop – criteria evaluation matrix*

| Criteria evaluation | 2.a. PV residential rooftop |
|---|---|
| Winter impact | W |
| Implementing speed | QQQ |
| Resilience | RRR |
| Cost (LCOE, wintertime 2 years lifetime) | C |
| General score (1-3) | 1.7 |
| General scores (excl. cost) (1-3) | 2.1 |

**Winter impact (production at wintertime)**

Solar PV systems generate more electricity during the summer than in winter due to fewer hours of sunlight, with only about 30% of the total annual production occurring during the winter months. The average capacity factor during winter is app. 8%, while the annual capacity factor is 14%. The potential for PV generation also varies across the country as illustrated by the winter production map in Figure 11. This seasonal pattern is consistent across all PV technologies, with no significant variation among different sub-technologies within the category.

**Implementing speed (Q)**

In principle, a residential PV can be commissioned in less than 5 weeks after the decision has been taken. The installation alone can be completed within a week. The preparation processes, including inspection and calculation to conclude if the construction of the roof is appropriate for installing the modules, can also be conducted in a day or two. Furthermore, the delivery time is relatively short and is estimated to be less than 2 weeks in most cases. It is not necessary to include time spent obtaining permits; consumers can install electricity generation units for self-consumption without a license. Homeowners can obtain active consumer status by entering into specific agreements. These include electricity purchase and sale agreements under the self-generation mechanism or contracts with guaranteed buyers or universal service providers to sell electricity at a feed-in tariff. While these agreements require additional time, they are not mandatory for commissioning residential PV plants.

**Resilience (R)**

Residential PV systems demonstrate considerable resilience in the face of potential threats, such as Russian strikes, owing to their dispersed layout. Solar PV technology offers significant potential for decentralized energy production. In the current Ukrainian context, distributed solar PV installations near demand centres provide advantages such as reduced dependence on the transmission grid, mitigating risks associated with potential power production capacity loss. Additionally, operation and maintenance do not require highly specialized personnel, making it easier to mobilize Ukrainian teams for servicing. Restoration of solar PV systems is straightforward and relatively fast due to their modular design, allowing single panels to be replaced **quickly**, enabling the system to resume operation in a short time.

**Generation costs (LCOE), short term and over the lifetime (C)**

Residential PV technology exhibits one of the least competitive Levelized Cost of Electricity (LCOE) when analysed over the short term (2 years) and only for wintertime production. This is due to the high capital cost and low production in wintertime. Seen over the entire lifetime, the LCOE for PV is on the other hand among the lowest among the technologies analysed.

#### 4.3.1.3. Data sheet

In Appendix F.

### 4.3.2. PV commercial and public, rooftop and ground mounted

#### 4.3.2.1. Brief technology description

PV commercial and public, rooftop and ground mounted refers to a solar PV system installed on the roof or on the ground in relation to commercial or public buildings. This system is designed to capture sunlight and convert it into electricity for on-site use or to feed back into the grid. It typically comprises of solar panels, inverters, grid connections, mounting structures, and monitoring equipment that tracks the performance of the PV installation.

Scale and Capacity: PV on commercial, industrial, and public rooftops range from small-scale installations to large projects, depending on the energy demand and available space. In this assessment, it is assumed that the total capacity is up to around 100 kW.

A variation that is considered in this analysis is the combination of a PV and an energy storage (a Lithium-ion battery) to store surplus electricity for use during periods of low sunlight or as a backup power source.

## 4.3.2.2. Criteria evaluation

*Table 13: PV commercial, industrial, and public rooftop – criteria evaluation matrix*

| Criteria evaluation | 2.a. PV residential rooftop | 2.b.5.b PV comm. & industrial – with battery |
|---|---|---|
| Winter impact | W | W |
| Implementing speed | QQQ | QQQ |
| Resilience | RRR | RRR |
| Cost (LCOE, wintertime 2 years lifetime) | C | C |
| General score (1-3) | 1.7 | 1.6 |
| General scores (excl. cost) (1-3) | 2.1 | 2.1 |

**Winter impact (production at wintertime)**

Solar PV systems generate more electricity during the summer than in winter due to fewer hours of sunlight with only about 30% of the total annual production occurring during the winter months. The average capacity factor during winter is app. 8%, while the annual capacity factor is 14%. The potential for PV generation also varies across the country as illustrated by the winter production map in Figure 11. This seasonal pattern is consistent across all PV technologies, with no significant variation among different sub-technologies within the category.

**Implementing speed (Q)**

The development of a commercial-scale solar PV project involves several key steps, including conducting preliminary feasibility and roof/land inspections, and performing technical and economic feasibility studies. Conducting Technical and Economic Feasibility Study (TEFS) and Project and Cost Estimate Documentation (PCED) varies based on the need of detailed analysis required. It is common to do a PCED to start with. Tenders for construction are announced, leading to the project's operation and transfer to local municipal companies for ongoing maintenance.

The timeframe for solar PV installations varies based on factors such as manufacturer, model, and order volume, ranging from weeks to months. In commercial-scale solar projects, the feasibility study takes about 5-7 days, inspections around 10 days, TEFS approximately one month, and PCED about 1.5 months (up to 4 months in less favourable circumstances). In the tendering process, contractors are required to maintain necessary equipment in stock and ensure delivery within 7 days during the tendering process.

The duration of the installation is assumed to be 3 to 4 weeks.

Summing up to a total implementing time of approximately a little more than 20 weeks.

**Resilience (R)**

Commercial and public PV showcase **high** resilience in the face of potential threats, such as Russian strikes, owing to their dispersed layout. Solar PV technology presents significant potential for decentralized energy production. In the current Ukrainian context, distributed solar PV installations located near demand offer advantage such as reduced dependence on the transmission grid, mitigating risks associated with potential power production capacity loss. Operation and maintenance of solar PV installations do not require exceptionally specialized workforce making it easier to gather Ukrainian teams to service solar installations.

Restoration of solar PV systems is relatively fast and easy due to their modular design, allowing single panels to be replaced **quickly**, enabling the system to resume operation in a short time.

Combining PV with batteries does not affect the resilience. The batteries can be installed underground or be sheltered, despite a considerable demand for cooling.

**Generation costs (LCOE), short term and over the lifetime (C)**

Commercial and public scale PV technology exhibits among the least competitive Levelized Cost of Electricity (LCOE) when analysed over the short term (2 years) and only for wintertime production. This is due to the high capital cost and low production in wintertime. Seen over the entire lifetime, the LCOE for PV is on the other hand among the lowest among the technologies analysed.

## 4.3.2.3. Data sheet

In Appendix F.

## 4.3.3. PV utility-scale

## 4.3.3.1. Brief technology description

PV utility-scale refers to large-scale PV solar power generation systems that are designed and deployed to supply electricity to utility companies or the electrical grid. PV utility-scale systems are characterized by their substantial solar panel arrays, typically covering several hectares of land. In average for 1 MW (DC) solar panel capacity there is a need for 1 hectares of land.

## 4.3.2.2. Criteria evaluation

*Table 14: PV utility-scale – criteria evaluation matrix*

| Criteria evaluation | 2.c. PV utility scale, ground mounted |
|---|---|
| Winter impact | W |
| Implementing speed | QQ |
| Resilience | RRR |
| Cost (LCOE, wintertime 2 years lifetime) | CC |
| General score (1-3) | 1.7 |
| General scores (excl. cost) (1-3) | 1.6 |

**Winter impact (production at wintertime)**

Solar PV systems generate more electricity during the summer than in winter due to fewer hours of sunlight, with only **about 30%** of the total annual production occurring during the winter months. The average capacity factor during winter is app. 8%, while the annual capacity factor is 14%. The potential for PV generation also varies across the country as illustrated by the winter production map in Figure 11. This seasonal pattern is consistent across all PV technologies, with no significant variation among different sub-technologies within the category.

**Implementing speed (Q)**

The implementation speed of a utility-scale solar PV is set to **moderate**. The development of a utility-scale solar PV involves several key steps, including identifying potential sites, securing land rights, screening the electrical grid's capacity, designing, obtaining permits, negotiating power purchase agreements, securing financing, procuring equipment, and finally, construction and test operations. The planning phase in total is assessed to take a little more than 1 year.

If experienced construction companies are available, the solar park can be constructed within a time frame of approximately 6 months. Challenges include delays in grid connection, shortage of skilled engineers, and transportation obstacles. The delivery time for solar PV modules is in general short because they can be found in large numbers in warehouses in Europe. The delivery time of inverters and the rest of the installations varies but is in general short. The Ukraine's infrastructure could pose challenges, but because of the modular structure, no parts of event large PV plants need to be transported as special transport. Despite ongoing war, solar PV installations continue in Ukraine, emphasizing the need for a proficient workforce. Integration into the electricity grid requires well-developed infrastructure, facing challenges from attacks on the grid during the war with Russia.

However, it is concluded that the total period from the beginning of the planning phase to operation is almost 2 years.

**Resilience (R)**

The resilience of utility scale PV is assessed to be **good**. In the current Ukrainian context, distributed solar PV installations located near demand centres offer advantages such as reduced dependence on the transmission grid, mitigating risks associated with potential power production capacity loss. Localized power generation enhances energy security by minimizing the need for extensive electricity transmission.

Operation and maintenance of solar PV installations do not require exceptionally specialized workforce making it easier to gather Ukrainian teams to service solar installations. The resilience could be increased by including at least a two-year mandatory service contracts within tender specifications.

During war, protective structures, shelters, camouflage, or underground bunkers can be employed to protect the transformer station, but the possibility for protecting the modules is limited, and it could be assumed that risk for that the utility scale PV plant is seen as a target is higher.

Restoration of solar PV systems is relatively fast and easy due to their modular design, allowing single panels to be replaced **quickly**, and enabling the system to resume operation in a short time.

**Generation costs (LCOE), short term and over the lifetime (C)**

Utility scale PV receives the **medium** score when analysing the Levelized Cost of Electricity (LCOE) over the short term (2 years) and only for wintertime production. This is due to a lower capital cost per MW compared to smaller installations of PVs; there is however still low production in wintertime.

Seen over the entire lifetime, the LCOE for PV is on the other hand among the lowest among the technologies analysed.

### 4.3.3.3. Data sheet

In Appendix F.

# 4.3.4. PV floating utility-scale

## 4.3.4.1. Brief technology description

Floating utility-scale PV refers to large-scale photovoltaic solar installations that are situated on bodies of water, such as dams and reservoirs, using floating platforms. In case, they are placed on the surface of the dam of hydro power plants, transformers and grid can be shared that is an advantage for the economy. The key difference to ground mounted utility scale PV system is the specially designed floating structures or platforms that are used to support solar panels on the water's surface. If the PV could benefit from the more defuse radiation due to the reflection on the surface of the dam has not yet been documented.

As for the ground mounted utility scale PV Floating solar installations are typically connected to the electrical grid, allowing the generated electricity to be distributed and utilized as needed. Inverter systems are employed to convert the direct current (DC) electricity generated by the solar panels into alternating current (AC) suitable for the grid.

## 4.3.4.2. Criteria evaluation

*Table 15: PV utility-scale floating – criteria evaluation matrix*

| Criteria evaluation | 2.d. PV utility scale, floating |
|---|---|
| Winter impact | W |
| Implementing speed | Q |
| Resilience | RRR |
| Cost (LCOE, wintertime 2 years lifetime) | CC |
| General score (1-3) | 1.5 |
| General scores (excl. cost) (1-3) | 1.6 |

**Winter impact (production at wintertime)**

Solar PV systems generate more electricity during the summer than in winter due to fewer hours of sunlight, with **only about 30%** of the total annual production occurring during the winter months. The average capacity factor during winter is app. 8%, while the annual capacity factor is 14%. The potential for PV generation also varies across the country as illustrated by the winter production map in Figure 11. This seasonal pattern is consistent across all PV technologies, with no significant variation among different sub-technologies within the category.

**Implementing speed (Q)**

The implementation speed of a floating utility-scale solar PV is set to **poor**. The development of a floating utility-scale solar PV involves several key steps, including identifying potential sites, securing land rights, screening the electrical grid's capacity, designing, obtaining permits, negotiating power purchase agreements, securing financing, procuring equipment, and finally, construction and test operations. The steps before ordering and construction are expected to take more than 1 year.

Given that floating PV is a relatively new technology, it could be a challenge to find and hire experienced construction companies. Therefore, it is assumed that it may take slightly longer to construct a floating solar park than a ground mounted, but that it can still be completed within approximately 8 months. Challenges include delays in grid connection, shortage of skilled engineers, and transportation obstacles. The delivery time of inverters and the rest of the installations varies but is in general short. The Ukraine's infrastructure could pose challenges, but because of the modular structure, no parts of even large PV plants need to be transported as special transport. Integration into the electricity grid requires well-developed infrastructure but could be faster if placed on a dam of a hydro plant, where the installations' sufficient capacity is already available.

It is concluded that the total period from the beginning of the planning phase to operation is more than 2 years.

**Resilience (R)**

The resilience of floating utility scale PV is assessed to be **moderate**. In the current Ukrainian context, distributed solar PV installations located near demand centres offer advantages such as reduced dependence on the transmission grid, mitigating risks associated with potential power production capacity loss. Localized power generation enhances energy security by minimizing the need for extensive electricity transmission.

Operation and maintenance of solar PV installations do not require exceptionally specialized workforce making it easier to gather Ukrainian teams to service solar installations. The resilience could be increased by including at least a two-year mandatory service contracts within tender specifications.

During war, protective structures, shelters, camouflage, or underground bunkers can be employed to protect the transformer station, but the possibility for protecting the modules is limited, and it could be assumed that risk for that the utility scale PV plant is seen as a target is higher than for the smaller PV systems.

Despite the added complexity of a water-based setup, floating solar PV systems can be restored efficiently thanks to their modular design. Individual panels can be replaced **quickly**, allowing the system to return to operation with minimal disruption.

**Generation costs (LCOE), short term and over the lifetime (C)**

Utility scale floating PV technology receives the **medium** score when analysing the Levelized Cost of Electricity (LCOE) over the short term (2 years) and only for wintertime production. This is due to a lower capital cost per MW compared to smaller installations of PVs; there is however still low production in wintertime.

Seen over the entire lifetime, the LCOE for floating PV receives the best grading.

### 4.3.4.3. Data sheet

In Appendix F.

## 4.3.5. PV parameter evaluation

Due to their similarities, the parameter evaluation covers all sub-technologies of the PV segment. Where possible a distinction is made.

*Table 16: Photovoltaic technologies – parameter evaluation matrix. The LCOE unit is [€/MWh]*

| Parameters | 2.a. PV residential rooftop | 2.b.5.b PV comm. & industrial – with battery | 2.b. PV comm. & industrial | 2.c. PV utility scale, ground mounted | 2.d. PV utility scale, floating |
|---|---|---|---|---|---|
| P1-Electricity production at wintertime | <30% | <30% | <30% | <30% | <30% |
| P2-Levelized Cost of Electricity (LCOE) short lifetime, winter production [€/MWh] | 3 320 | 3 187 | 2 300 | 1 512 | 1 828 |
| P3-Levelized Cost of Electricity (LCOE) over lifetime [€/MWh] | 66 | 62 | 46 | 34 | 41 |
| P4-Distributed generation | Good | Good | Good | Medium | Medium |
| P5-Regulation requirement in the project development process | Quick and easy | Quick and easy | Quick and easy | In between | In between |
| P6-Delivery time and availability of components and materials | Quick and easy | Quick and easy | Quick and easy | In between | In between |
| P7-Requirements for logistics and transportation infrastructure | Low | Low | Low | Low | Low |
| P8-Technical installation time (after clearance) | Quick and easy | Quick and easy | Quick and easy | Quick and easy | Medi-um-term |
| P9-Requirements for skilled staff in construction phase | Low | Low | Low | Low | Low |
| P10-Grid balancing capacity | Low | Medium | Low | Low | Low |
| P11-Requirements for electricity grid infrastructure | Easy | Easy | Easy | Challeng-ing | Challeng-ing |
| P12-Requirements for skilled staff for operation and mainte-nance and for special spare parts | Low | Low | Low | Low | Low |
| P13-Possibility for camouflage and sheltering | High | High | High | Medium | Medium |
| P14-Risk associated with fuel supply | Low risk | Low risk | Low risk | Low risk | Low risk |
| P15-Restoration time | Quick and easy | Quick and easy | Quick and easy | Quick and easy | In between |

**P1: Electricity production at wintertime:**

Solar PV generally produce more during summertime than during the winter period[15]. Only 30% of the total production is in winter. The average capacity factor during winter is app. 8%, while the annual capacity factor is 14%. Obviously, the production depends on the specific location. Figure 11 shows the expected annual wintertime PV generation in full load hours (FLH: MWh per MW installed capacity) in different regions of Ukraine.

15 October to March

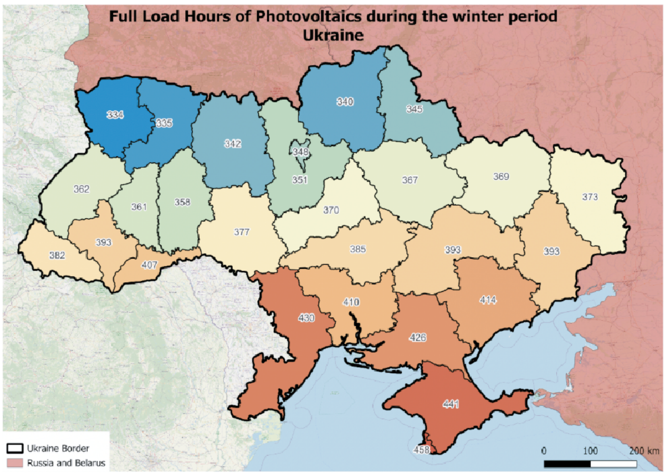



*Figure 11 : Expected wintertime PV generation (MWh per MW installed capacity) in different regions of Ukraine. Wintertime production of 350 MWh/MW corresponds to app. 30% of the annual production and a capacity factor of 8%. The maps are set up calculating the generalized power generation from photovoltaics in the different Ukrainian regions, Global Solar Atlas covering the period between 1994 and 2018 was used.*

**P2: Levelized Cost of Electricity (LCOE) short lifetime, winter production (C)**

The Levelized Cost of Electricity generation over two winters (emergency perspective) amounts to approximately:

- 3 320 €/MWh for PV residential rooftop
- 3 187 €/MWh for PV comm. & industrial – with battery
- 2 300 €/MWh for PV comm. & industrial
- 1 512 €/MWh for PV Utility-scale
- 1 828 €/MWh for Floating PV

This is significantly higher than for all other technologies included in this analysis. This is due to the high upfront capital costs and the low production during winter.

**P3: Levelized Cost of Electricity (LCOE) over lifetime (C)**

On the other hand, solar PV technology shows low Levelized Cost of Electricity (LCOE) when considering production all year round and the project's expected lifetime that spans a minimum of 30 years, barring any unforeseen events:

- 70 €/MWh for PV residential rooftop
- 95 €/MWh for PV comm. & industrial – with battery
- 70 €/MWh for PV comm. & industrial
- 60 €/MWh for PV Utility-scale
- 65 €/MWh for Floating PV

Which shows that LCOE over the lifetime of PV is in general lower than for all other technologies included in these analyses, except for wind and hydro. Combining with batteries, the LCOE increases by approximately 35%. The value of increasing the own consumption of the production from the PV by combining with a battery is not included in the LCOE calculation.

**P4: Distributed generation (R)**

Solar PV technology holds substantial generation potential as a scalable choice for decentralized energy production. Solar PV installations can vary in size, spanning from a few watts to multiple megawatts.

Given the current situation in Ukraine, there are several compelling reasons to favour distributed solar PV installations. These installations, located near demand centres, offer the advantage of reducing dependence on the transmission grid, thereby mitigating the risks associated with potential power production capacity loss. Moreover, local power generation at the end-user's site diminishes the necessity for extensive electricity transmission, consequently bolstering energy security.

**P5: Regulation requirement in the project development process (Q)**

In general, if solar panels are installed on **single-family dwellings** and the production does not exceed the family's own consumption limits, it is not needed to seek approval or licensing.

The preparation processes for residential PV include inspection and calculation to determine if the construction of the roof is appropriate for installing the modules that could also be conducted in a day or two. It is not necessary to include time spent obtaining permits, because consumers can install electricity generation units for self-consumption without a license. However, it is possible to enter into agreements to get an active consumer status achieved by signing electricity purchase and sale agreements under the self-generation mechanism, and agreements with guaranteed buyers or universal service providers for selling electricity at a feed-in tariff, this will cost extra time, but that is not necessary for bringing the residential PV plants into operation.

The development of a **commercial-scale solar PV** project typically involves the following steps:

1. Preliminary Feasibility Study: This involves a theoretical assessment of the potential for installing a station, based on basic energy consumption data, building photos, and other consumption-related information. It provides an initial evaluation of the necessary investment, project benefits, projected electricity production costs, and energy offset. The preliminary feasibility study could be conducted within 5-7 days.
2. Roof Inspection Report or Land Inspection Report: These reports are more comprehensive and typically funded by the city council or entity interested in acquiring the project. Certified engineers prepare these reports, ensuring that the structure can support the installation. This step is crucial to prevent unexpected expenses for structural modifications later in the process. Roof inspections typically take about 10 days to complete. For land inspections, the focus is on communication infrastructure and potential limitations, such as gas pipelines or other project-affecting factors.
3. Conducting a Technical and Economic Feasibility Study (TEFS) or Creating Project and Cost Estimate Documentation (PCED): The choice between these options depends on various factors. If there is certainty about available project funding, it is common to proceed directly to PCED. If a potential investor commits to funding the project regardless of potential additional factors, PCED may also be the starting point. However, if a more detailed analysis is required, the process begins with a TEFS. This involves an engineer conducting a thorough site inspection and performing detailed calculations based on various scenarios, accounting for factors such as panel quantity and electrical network quality. A TEFS could take about 1 month while PCED could take from 1.5 months to 4 months.
4. Announcing Tenders for Construction. It is considered that a 30 kW plant could be built within 7-10 days, and a 100 kW plant in about 15-18 days if no critical issues arise. Subsequent documentation processes depend on the parties involved and how quickly they want to close the matter.

The development of a **utility-scale solar** PV farm typically involves the following steps:

1. Screening Phase: This initial phase entails assessing the capacity and availability of the electrical grid to connect the solar park to the power system. Grid integration studies are conducted to ensure the grid can accommodate the injected power from the solar PV at the chosen connection point. The results of these grid studies are crucial before a solar power developer can commit to a specific project. Depending on the park's location, the wait time for grid connection can be substantial.
2. Development Phase: During this stage, potential sites for the solar park are identified, and the necessary land rights from landowners are secured, either through land purchase or leasing. It is recommended to engage in consultations with neighbours and discuss specific conditions relevant to PV installations to ensure local support before initiating political processes.

3. Solar Park Design and Permitting: This phase involves designing the layout and size of the solar park, as well as obtaining all the required permits and approvals from regulatory agencies. Environmental impact assessments (EIA) are not mandatory for solar power projects.

4. Power Purchase Agreements: This phase includes negotiating contracts with utilities or other off takers to sell the electricity generated by the solar park.

5. Financing: In this step, funding is secured from investors or lenders to cover the costs of developing, constructing, and operating the solar park.

6. Procurement: This phase involves acquiring or leasing all the necessary equipment, materials, and services for building and operating the solar park. The delivery time for new solar panels is typically less than 10 weeks, but for the transformer and inverters, in some cases, it can extend up to 2 years. This phase also involves contracting with local construction companies for civil works, roads, construction sites, and electrical infrastructure.

7. Construction and putting into Operations: This phase encompasses the construction, testing, commissioning, and operation of the solar park over its lifetime. If experienced construction companies are available, the solar park can be constructed within a time frame of approximately 6 months.

To reduce the process for utility-scale solar farms, one effective approach is to commence projects that have already undergone exhaustive due diligence.

**P6: Delivery time/availability of components and materials (Q)**

In general, PV modules are in stock on the market in the EU, and thereby easily available. However, the delivery timeframe for solar PV installations in Ukraine can vary from a matter of weeks to several months, partly depending on the scale of the installation.

**P7: Requirements for logistics and transportation infrastructure (Q)**

The transportation of solar PV components, including panels, inverters, and mounting equipment, do not in general require specialized vehicles, equipment, and routes, depending on the installation's size, while it in general can be divided into modules. Although, Ukraine's logistics and transportation infrastructure can present challenges for due to subpar road conditions in certain regions, port and crane damages, and security concerns in war-affected areas.

**P8: Technical installation time (min time after clearance) (Q)**

Construction and test operations: This phase encompasses the construction, testing, and commissioning. If experienced construction companies are available, the solar park can be constructed within a time frame of approximately 6 months. While residential PV plants can be installed in less than a week and commercial/public PV plants in less than 3 weeks depending on the size.

**P9: Requirements for skilled staff in construction phase (Q)**

The construction of PV installations necessitates a proficient workforce spanning multiple disciplines, including engineering, project management, procurement, installation, commissioning, quality control, health and safety, and environmental protection. But not to the same extent as for large wind power.

However, the installation of mounting systems requires a certain level of expertise. Mentioned as an advantage is contracting experienced workforce not at least when it comes to putting up the mounting system.

Based on previous experience of erecting about 6.6 GW of PV capacity, it is expected that skilled staff will be available. Despite that, it has been mentioned that the lack of qualified technical supervision experts for quality assessment of construction and installation is a challenge in Ukraine at the moment.

**P10: Grid balancing capacity (R)**

The grid balancing capacity for PV is low. However, PV plants may provide downregulation if generating or upregulation if not generating at maximum capacity. Usually, PV plants would operate at maximum capacity since this would maximize earnings in the power market under normal conditions. The PV could support the grid, by supplying electricity at distributed level near the consumers.

**P11: Requirements for electricity grid infrastructure (R)**

The integration of utility scale PV into the electricity grid necessitates the presence of well-developed transmission and distribution lines, substations, balancing and ancillary services, as well as the implementation of smart grid technologies. It's crucial to note that Ukraine's electricity grid infrastructure has faced challenges, including attacks on its electricity infrastructure by missiles and drones from Russia during the ongoing war.

A significant aspect is the need for seamless integration of solar energy into the power grid without overburdening it. Consequently, it becomes imperative to adopt a regional approach, precisely outlining the strategic deployment of solar energy, thus ensuring its effective and efficient incorporation into the national energy landscape. This approach shall aim to address the challenges of grid integration and coordinated planning for the sustainable growth of solar energy in Ukraine.

**P12: Requirements for skilled staff for operation and maintenance and for special spare parts (R)**

The operation and maintenance of solar PV installations typically do not demand an exceptionally skilled and specialized workforce, making it relatively straightforward to assemble a Ukrainian team capable of servicing the solar installation. However, it's important to emphasize that a security company is imperative to provide round-the-clock protection for the PV plant, as the risk of theft is considerably high, a challenge common to all PV (and hydro) installations in Ukraine.

In tender specifications, it is highly recommended to stipulate the inclusion of a mandatory service contract for at least the initial 2 years. Moreover, considering a service contract for professional maintenance beyond this period is also advisable. Presently in Ukraine, service technicians conduct biannual visits to solar installations, primarily to assess the quality of connections, ensure the absence of issues, and address any emerging concerns.

**P13: Possibility for camouflage and sheltering (R)**

It is not possible to camouflage or shelter utility scale PV due to their size, but it is possible to protect critical components such as transformer stations with fences and/or by establishing them underground in bunkers or by protecting them with concrete roofs.

The size and production of the residential and, to some extent, the commercial and public PV is relatively low, thereby, the importance for the electricity system limited; therefore, the risk for these being enfiladed is assessed to be relatively low than for the larger plants.

The map provided below illustrates the potential reach of Russian artillery and close-range ballistic missiles (CRBM). It becomes evident that a substantial portion of Ukraine, with the exception of the central regions, falls within the CRBM range. Even in these relatively safer areas, the energy infrastructure remains susceptible to potential drone attacks or longer-range missile strikes. Notably, the maps (in the two figures below) also underscore that the central regions of Ukraine that face a lower risk of Russian artillery or missile attacks continue to offer reasonable electricity generation potential, even during the winter season.

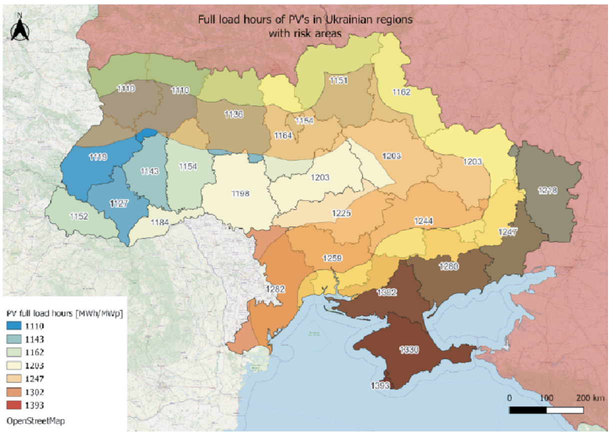



*Figure 12: Expected annual PV generation (MWh per MW installed capacity) in different regions of Ukraine. An annual production of 1 200 MWh/MW corresponds to a capacity factor of 14%. Buffer zones of 100 km and 280 km were applied from Russian controlled areas and Belarus, accounting for the longest range of Russian artillery and CRBMs (close range ballistic missiles). The maps are set up calculating the generalized power generation from photovoltaics in the different Ukrainian regions, Global Solar Atlas covering the period between 1994 and 2018 was used.*

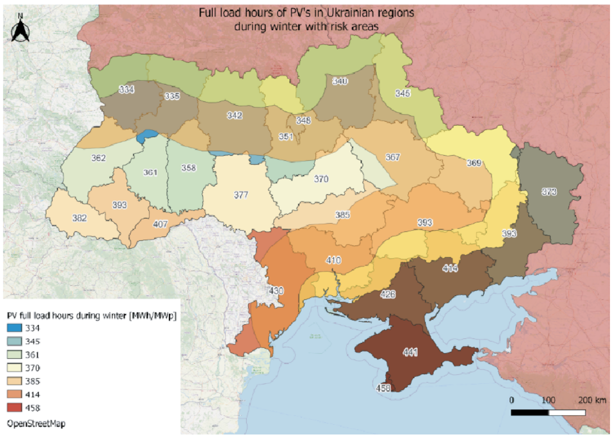



*Figure 13: Expected wintertime PV generation (MWh per MW installed capacity) in different regions of Ukraine. And wintertime production of 350 MWh/MW corresponds to app. 30% of the production and a capacity factor of 8%. Buffer zones of 100 km and 280 km were applied from Russian controlled areas and Belarus, accounting for the longest range of Russian artillery and CRBMs (close range ballistic missiles). The maps are set up calculating the generalized power generation from photovoltaics in the different Ukrainian regions, Global Solar Atlas covering the period between 1994 and 2018 was used.ng the period between 1994 and 2018 was used.*

**P14: Risk associated with fuel supply (R)**

Not relevant.

**P15: Restoration time**

Restoration of solar PV systems is relatively fast and easy due to their modular design, allowing single panels to be replaced quickly, enabling the system to resume operation in a short time.

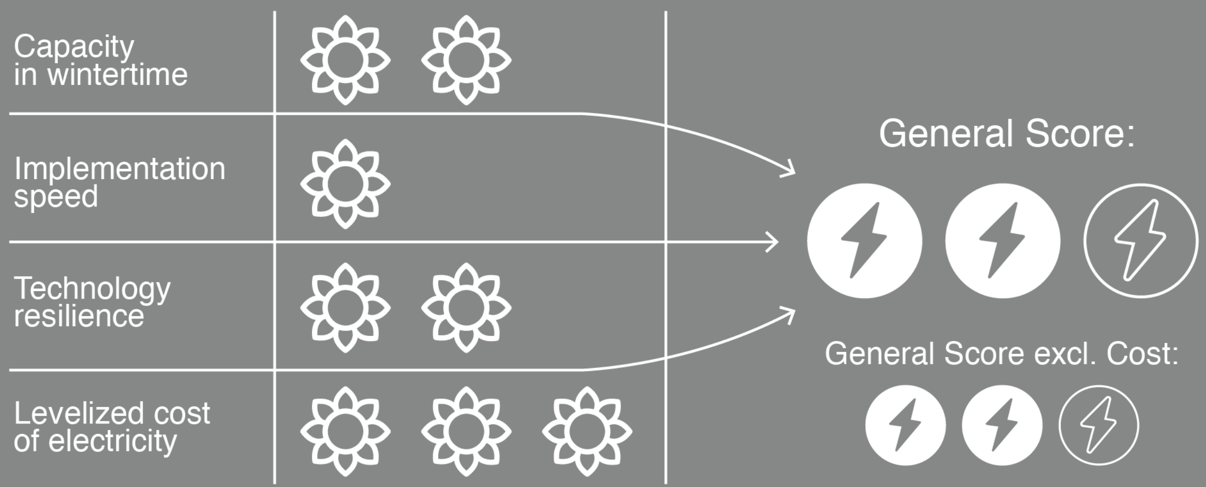
## 4.3.6. Additional technology-specific insights from the interviews

Achieving a comprehensive large-scale transition towards green energy sources necessitates the attainment of cost competitiveness with conventional oil and gas alternatives. A pivotal factor in this transition involves the identification of reliable partners who possess bankable Power Purchase Agreements (PPAs).

According to insights from interviewed Ukrainian experts, the investment landscape in Ukraine is characterized by a scarcity of purely financial investments solely driven by profit motives. Instead, stakeholders are often participants in co-financing endeavours, wherein they contribute equipment or financial resources, or provide support to Ukrainians in multifaceted ways. These contributors play an integral role in facilitating and advancing sustainable projects within the Ukrainian landscape. E.g., the United Nations Development Programme on Energy service companies (UNDP ESCO) objectives aimed at enabling such investments[16].

16 https://www.undp.org/ukraine/publications/overview-best-practices-esco-market-design-and-recommendations-ukraine

# ONSHORE WIND



# 4.4. Onshore Wind

The rating on the front page shows the score for the technology achieving the highest general score among the sub technologies evaluated in the chapter. The more icons, the better performance[17]. For wind technologies, the "used onshore wind turbine farm" and the "household wind turbines" achieve the best score. The scores for all sub-technologies are shown in Table 17.

*Table 17: Wind Power – Overall criteria evaluation matrix*

| Criteria evaluation | 3.a. Wind onshore farms (>20 MW) | 3.b. Used wind onshore farms (>20 MW) | 3.c. Wind onshore cluster (4.2-20 MW) | 3.d. Wind household turbines (<100 kW) |
|---|---|---|---|---|
| Winter impact | WW | WW | WW | WW |
| Implementing speed | Q | Q | Q | QQQ |
| Resilience | RR | RR | RR | RRR |
| Cost (LCOE, wintertime 2 years lifetime) | CCC | CCC | CCC | C |
| General score (1-3) | 2.0 | 2.1 | 2.0 | 1.9 |
| General scores (excl. cost) (1-3) | 1.8 | 1.9 | 1.9 | 2.4 |

This chapter covers four different types of onshore wind technologies:

- Onshore wind farm (20-100 MW)
- Cluster of onshore wind turbines (5-20 MW)
- Used wind turbines for onshore wind farm (20-100 MW)
- Household wind turbines (<100 kW)

The first three technologies are all MW scale technologies, and their characteristics, challenges, and opportunities are largely the same. Therefore, these technologies are treated together in most of the sections in the chapter.

Household wind turbines on the other hand are on the kW scale and intrinsically different from the large turbines, both regarding the technology and approval process, and are therefore considered in a separate chapter.

## 4.4.1. Onshore wind turbines (MW scale)

### 4.4.1.1. Brief technology description

Because of their similarities, this section covers onshore wind farm (20-100 MW), clusters of onshore wind turbines (5-20 MW), and used wind turbines for an onshore wind farm (20-100 MW).

The typical onshore wind turbine being installed today is a horizontal axis, three bladed, upwind, grid connected turbine using active pitch, variable speed, and yaw control to optimize generation at varying wind speeds.

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[17] See detailed explanation in Table 2: Overview of the parameters contributing to each criterion, along with the corresponding ratings. The number of icons represents the quality of the rating, with more icons indicating a better rating.

Wind turbines work by capturing the kinetic energy in the wind with the rotor blades and transferring it to the drive shaft. The drive shaft is connected either to a speed-increasing gearbox coupled with a medium- or high-speed generator, or to a low-speed, direct-drive generator. The generator converts the rotational energy of the shaft into electrical energy. In modern wind turbines, the pitch of the rotor blades is controlled to maximize power production at low wind speeds, and to maintain a constant power output and limit the mechanical stress and loads on the turbine at high wind speeds. A general description of the turbine technology and electrical system, using a geared turbine as an example, can be seen in Figure 14.

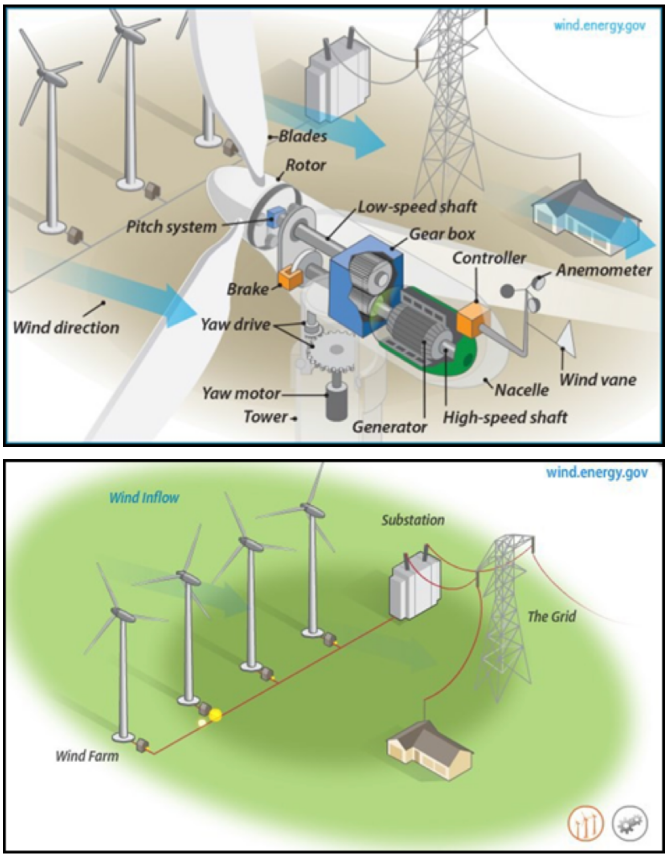



Figure 14: General wind turbine technology and electrical system

Three major parameters define the design of a wind turbine. These are hub height, nameplate capacity (or rated power), and rotor diameter. The last two are often combined in a derived metric called “specific power”, which is the ratio between nameplate capacity and swept area. The specific power is measured in $W/m^2$.

At the beginning of 2020, the total installed capacity of Ukrainian wind farms was 1.17 GW. The wind resource in Ukraine is ample, and studies have shown that Ukraine could potentially host more than 600 GW of wind capacity.

Figure 15: Four Vestas 3 MW wind turbines

Figure 16 shows the expected annual wind turbine generation (MWh per MW installed capacity) in different regions of Ukraine. To calculate the generalized power generation from wind turbines in different Ukrainian regions, a raster map covering all of Ukraine was used. The raster map originated from Global Wind Atlas. The raster map contains the yearly capacity factor of wind turbines in the class IEC2[18]. More details on the calculation methodology can be found in Appendix E.

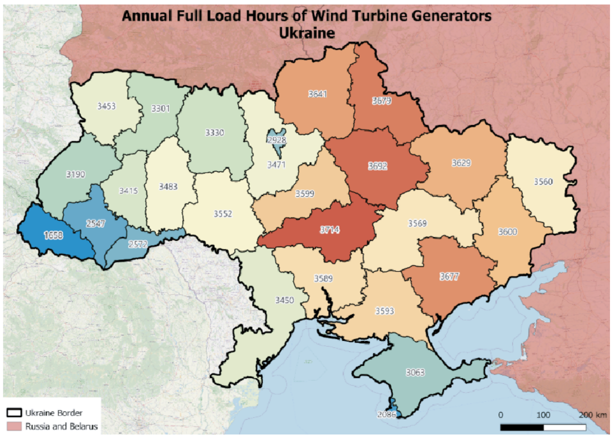



*Figure 16: Wind resource chart, expected annual wind turbine generation (MWh per MW installed capacity) in different regions of Ukraine. An annual production of 3 500 MWh/MW corresponds to a capacity factor of 40%s used.ng the period between 1994 and 2018 was used.*

## 4.4.1.2. Criteria evaluation

**Onshore wind farm (20-100 MW)**

*Table 18: Wind Power – criteria evaluation matrix for Onshore wind farm (20-100 MW)*

| Criteria evaluation | 3.a. Wind onshore farms (>20 MW) |
|---|---|
| Winter impact | WW |
| Implementing speed | Q |
| Resilience | RR |
| Cost (LCOE, wintertime 2 years lifetime) | CCC |
| General score (1-3) | 2.0 |
| General scores (excl. cost) (1-3) | 1.8 |

**Winter impact, production at wintertime (W)**

Onshore wind farm will be able to provide a significant contribution to the Ukrainian power system during wintertime. Obviously, production depends on the weather patterns, and there will be significant variations in generation over the winter season. However, Ukraine is a large country, and it is rarely calm everywhere. Large wind turbines demonstrate a capacity factor of about 40% during wintertime, meaning that on average 40% of the installed capacity can be utilized. Thereby almost 60% of the production is in wintertime (October-March).

[18] IEC Class 1 turbines are generally for wind speeds greater than 8 m/s. These turbines are tested for higher extreme wind speed and more severe turbulence. IEC Class 2 turbines are designed for average wind speeds of 7.5 m/s to 8.5 m/s. IEC Class 3 turbines are designed for winds less than 7.5 m/s. These turbines will need a larger rotor to capture the same amount of energy as a similar turbine at a Class II site. Source.

### Implementing speed (Q)

In principle, a wind farm may be erected within 6 months. However, the preparation processes are significant and involve environmental and legal permitting (1-2 years), delivery time for the wind turbines (up to 2 years), and feasibility studies and siting analysis (about 1 year). Under ideal conditions and relaxed environmental approval procedures, a green field wind farm project could be established within 2 years, but 4-5 years is a more realistic estimate for an onshore wind farm given the current framework conditions in Ukraine.

### Resilience (R)

Wind farms showcase considerable resilience in the face of potential threats, such as Russian strikes, owing to their dispersed layout. The transformer station connecting the wind farm to the high voltage power grid may be camouflaged or protected by a concrete ceiling. Therefore, it would require multiple attacks to take out a wind farm. Designing the wind farm with multiple 2-3 MW units, rather than fewer large units of perhaps 5-6 MW, would make the wind farm more resilient towards air strikes.

### Generation costs (LCOE), short term and over the lifetime (C)

Wind farms exhibit one of the most competitive Levelized Cost of Electricity (LCOE) profiles among all available energy technologies. Even in the short term, involving the generation over just two winters, wind energy is fairly a cost-efficient option, despite its initial capital investment.

### Cluster of onshore wind turbines (5-20 MW)

*Table 19: Wind Power – criteria evaluation matrix for Cluster of onshore wind turbines (5-20 MW)*

| Criteria evaluation | 3.c. Wind onshore cluster (4.2-20 MW) |
|---|---|
| Winter impact | WW |
| Implementing speed | Q |
| Resilience | RR |
| Cost (LCOE, wintertime 2 years lifetime) | CCC |
| General score (1-3) | 2.0 |
| General scores (excl. cost) (1-3) | 1.9 |

### Winter impact (production at wintertime)

Onshore wind farm may provide a significant contribution to the Ukrainian power system during wintertime. The production depends on the weather patterns and there will show significant variations in generation, however, Ukraine is a large country, and it is rarely calm everywhere. Large wind turbines demonstrate a capacity factor of about 40% during wintertime, meaning that on **average 40%** of the installed capacity can be utilized.

### Implementing speed

In principle, a wind farm may be erected within 6 months. However, the preparation processes are significant and involve environmental and legal permitting (1-2 years), delivery time for the wind turbines (up to 2 years), and feasibility studies and siting analysis (about 1 year). Under ideal conditions and relaxed environmental approval procedures, a green field wind farm project could be established within 2 years, but 3-4 years is a more realistic estimate for a cluster of onshore wind turbines given the current framework conditions in Ukraine. Compared to wind farms up to 100 MW, it might be easier to site smaller projects at locations where environmental and legal approval conditions are more favourable. Summing up, the process is lengthy, thus, the implementation speed score is **poor.**

### Resilience

Wind farms showcase considerable resilience in the face of potential threats, such as Russian strikes, owing to their dispersed layout. The transformer station connecting the wind farm to the high voltage power grid may be camouflaged or protected by a concrete ceiling. Therefore, it would require multiple strikes to take out a wind farm. Designing the wind farm with multiple 2-3 MW units, rather than a few large units of perhaps 5-6 MW, would make the wind farm more resilient towards air strikes. Thus, the resilience score is **medium.**

### Generation costs (LCOE), short term and over the lifetime

Clusters of wind turbines are among the most competitive of all available energy technologies. Even in the short term, involving the generation over just two winters, wind energy is a fairly cost-efficient option, despite its initial capital investment. Thus, the LCOE short time winter production score is **good.**

### Used wind turbines for an onshore wind farm (20-100 MW)

*Table 20: Wind Power – criteria evaluation matrix for Used wind turbines for an onshore wind farm (20-100 MW)*

| Criteria evaluation | 3.b. Used wind onshore farms (>20 MW) |
|---|---|
| Winter impact | WW |
| Implementing speed | Q |
| Resilience | RR |
| Cost (LCOE, wintertime 2 years lifetime) | CCC |
| General score (1-3) | 2.1 |
| General scores (excl. cost) (1-3) | 1.9 |

### Winter impact (production at wintertime)

Used wind turbines – typically 8-10 years old and with a capacity of 3 MW – applied in an onshore wind farm (20-100 MW) may provide a significant contribution to the Ukrainian power system during wintertime. The production depends on the weather patterns and there will significant variations in generation, however, Ukraine is a large country, and it is rarely calm everywhere. Large wind turbines demonstrate a capacity factor of about 40% during wintertime, meaning that on **average 40%** of the installed capacity can be utilized.

### Implementing speed

In principle, a wind farm may be erected within 6 months. However, the preparation processes are significant and involve environmental and legal permitting (1-2 years) and feasibility studies and sitting analysis (about 1 year). On the other hand, the delivery time for used wind turbines may, depending on the supplier, potentially be very short. Under ideal conditions and relaxed environmental approval procedures, a green field wind farm applying used wind turbines project could be established within 1.5-2 years, but 3-5 years is a more realistic estimate given the current framework conditions in Ukraine. Summing up, the process is lengthy, thus, the implementation speed score is **poor.**

### Resilience

Wind farms showcase considerable resilience in the face of potential threats, such as Russian strikes, owing to their dispersed layout. Since the transformer station connecting the wind farm to the high voltage power grid may be camouflaged or protected by a concrete ceiling, it would require multiple attacks to take out a wind farm. The upfront cost of a wind farm applying used wind turbines could be 30-40% lower than with new turbines, meaning less capital is at stake if the wind farm is attacked. Thus, the resilience score is **medium**.

**Generation costs (LCOE), short term and over the lifetime**

Measured over their technical lifetime, wind turbines are among the most competitive of all available energy technologies – and this is also the case for used wind turbines, which can be expected to showcase LCOE's equivalent to new turbines. In the short term, involving the generation over just two winters, used wind turbines are more cost-efficient than new turbines, owing to their initial investment costs, but still higher than for example gas turbines or gas engines. However, the LCOE short time winter production score is **good**.

## 4.4.1.3. Parameter evaluation of onshore wind turbines

*Table 21: Wind Power – parameters evaluation matrix for onshore (MW scale). The LCOE unit is [€//MWh]*

| Parameters | 3.a. Wind onshore farms (>20 MW) | 3.a. Used wind onshore farms (>20 MW) | 3.a. Wind onshore cluster (4.2-20 MW) |
|---|---|---|---|
| P1-Electricity production at wintertime | 50% | 50% | 50% |
| P2-Levelized Cost of Electricity (LCOE) short lifetime, winter production [€/MWh] | 785 | 553 | 901 |
| P3-Levelized Cost of Electricity (LCOE) over lifetime [€/MWh] | 38 | 35 | 42 |
| P4-Distributed generation | Medium | Medium | Good |
| P5-Regulation requirement in the project development process | Lengthy | Lengthy | Lengthy |
| P6-Delivery time and availability of components and materials | In between | Quick and easy | In between |
| P7-Requirements for logistics and transportation infrastructure | High | High | High |
| P8-Technical installation time (after clearance) | Medium-term | Medium-term | Medium-term |
| P9-Requirements for skilled staff in construction phase | Medium | Medium | Medium |
| P10-Grid balancing capacity | Medium | Medium | Medium |
| P11-Requirements for electricity grid infrastructure | Moderate | Moderate | Moderate |
| P12-Requirements for skilled staff for operation and maintenance and for special spare parts | Medium | Medium | Medium |
| P13-Possibility for camouflage and sheltering | Medium | Medium | Medium |
| P14-Risk associated with fuel supply | Low risk | Low risk | Low risk |
| P15-Restoration time | In between | In between | In between |

Due to their similarities, the quantitative parameter covers onshore wind farm (20-100 MW), clusters of onshore wind turbines (5-20 MW), and used wind turbines for an onshore wind farm (20-100 MW). Household wind turbines are evaluated in a separate section.

**P1: Electricity production in wintertime (W)**

The wind map shows that onshore wind turbines typically produce the same during winter and summer time, demonstrating a capacity factor of about 40%. Obviously, the production depends on the specific location. The abovementioned capacity factors assume that the wind turbines are erected in central and southern Ukraine, where the best wind conditions are found.

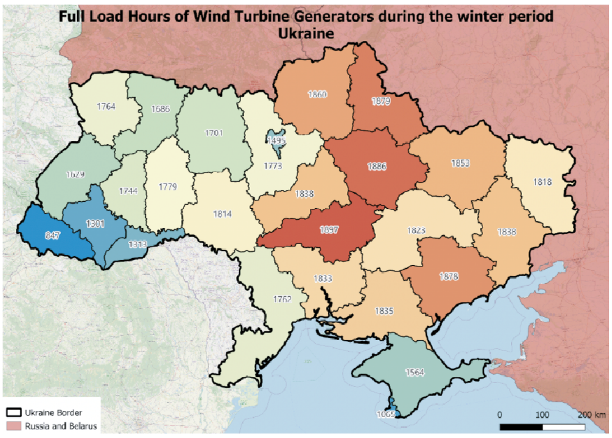



*Figure 17: Expected Wind turbine generation (MWh per MW installed capacity) in different regions of Ukraine during wintertime (which in this context is defined as October-March, 4 374 hours in total)*

**P2: Levelized Cost of Electricity (LCOE) short lifetime, winter production (C)**

The Levelized Cost of Electricity generation over two winters (emergency perspective) amounts to about 810 €/MWh for a wind farm (20-100 MW) and slightly higher, about €830/MWh for wind farm up to 20 MW. This is significantly higher than for gas engines or gas turbines, which demonstrate costs down to around €300-400/MWh but still significantly less than, for example, solar technologies, batteries, and certain biomass technologies.

The winter LCOE of used wind turbines could be about 30% lower than for new turbines due to lower upfront capital costs.

**P3: Levelized Cost of Electricity (LCOE) over lifetime (C)**

Onshore wind farms (20-100 MW) demonstrate low LCOEs over lifetime of around €35/MWh over the lifetime of the turbines, which is minimum 25 years in absence of unexpected events. Since scaling effects are moderate, the LCOE of wind turbines in smaller clusters up to about 20 MW is only expected to be about 10% higher.

The LCOE of used wind turbines is not expected to differ considerably from the LCOE of new turbines since the lower upfront capital costs are offset by shorter expected lifetime and (potentially) higher operation and maintenance costs.

**P4: Distributed generation (R)**

Onshore wind turbines are distributed over a relatively large area. Modern onshore wind turbines have installed capacity of 3 MW to 6 MW, and they are typically sited with a distance of between 300 to 500 meters depending on the size of the individual turbines. The fact that the turbines are spread over a large geographic area makes them less vulnerable to air strikes by artillery, missiles, or drones.

**P5: Regulation requirement in the project development process (Q)**

The development of an onshore wind farm typically involves eight steps:

1. Prospecting and land securing: This phase involves identifying potential sites for the wind farm and securing the necessary land rights from landowners. Since modern wind farms cover a large area with multiple landowners, this can be quite complicated. The prospecting would also involve analysis of soil conditions. In total, technical feasibility studies, excluding wind resource assessments, would take about 6 months to complete.

2. Wind-resource assessment: This phase involves measuring the wind speed and direction at the site to determine the potential energy output of the wind farm. Wind measurements may take about one year to be sufficiently reliable. However, the Ukrainian Wind Energy Association expects that by February 2024 an electronic wind atlas will be ready covering onshore and offshore wind. The atlas is prepared in cooperation with NREL and is based on measurements at heights of 100-120 meters. The atlas could replace

the need for physical measurements at site. Whether digital assessments are sufficient would often depend on the specific conditions set by the financing parties.

3. Interconnection and transmission studies: This phase involves evaluating the capacity and availability of the electrical grid to connect the wind farm to the power system.
4. Wind-farm design and permitting: This phase involves designing the layout, size, and number of wind turbines, as well as obtaining all necessary permits and approvals from regulatory agencies. The Ukrainian Wind Energy Association estimates that for wind farms the process of obtaining environmental permits will take about three years. This includes ornithological studies, bat studies, ecological surveys, and geological research. The requirements for environmental impact assessments (EIA) have been slightly relaxed during the martial law. Ornithological studies, however, have not been changed, and they take a minimum of one year. Other deadlines, such as hearings where interested parties can submit comments on specific projects, have been shortened by about half or one-third.
5. Power purchase agreements: This phase involves negotiating contracts with utilities or other off takers to sell the electricity generated by the wind farm.
6. Financing: This phase involves securing funding from investors or lenders to cover the costs of developing, constructing, and operating the wind farm.
7. Procurement: This phase involves purchasing or leasing all necessary equipment, materials, and services for building and operating the wind farm. Delivery time for new wind turbines is typically one year, in some cases up to 2 years. This phase involves contracting contracts with local construction companies for civil works, roads, construction sites, and electrical infrastructure.
8. Construction and operations: This phase comprises building, testing, commissioning, and operating the wind farm over its lifetime. The wind farm may be constructed within a time horizon of 6 months if experienced construction companies are available.

The process of developing a wind farm is expected to be more or less the same independently of the size of the wind farm and whether new or used turbines are applied.

**P6: Delivery time / availability of components and materials (Q)**

The delivery time for onshore wind turbines depends on the manufacturer, the model, and the order volume. It can range from 6 months to 2 years.

However, it is worth noting that used wind turbines can be supplied on short notice. Used wind turbines would typically be around 8-10 years old and have a capacity of about 3-4 MW. There is a mature market for used turbines, and it is deemed realistic that at least 100 MW of used wind power capacity from Europe may be procured.

Ukrainian stakeholders in the wind industry have expressed concerns about using used wind turbines for different reasons: potentially more expensive spare parts, reliability of the turbines, and lack of knowledge about how to service the old turbines. Therefore, it is important that any used turbines sold at the Ukrainian market are supplied with long-term guarantees or service contracts.

The overall time required for a project's delivery depends on many factors, such as size, complexity, access to the grid, regulatory framework procedures, etc. A typical renewable energy project, such as an onshore wind farm, may take three to five years to realize from planning to operation.

As a best estimate, developing a green field project in Ukraine would require minimum 2 years, even if used wind turbines are applied, electronic wind speed measurements are available, and the project may be exempt from a lengthy environmental impact assessment process. Under less favourable conditions, the total process may take up to five years.

If it is possible to resurrect wind farm projects already in process, but closed down or mothballed due to the war, this could allow for speedier project delivery.

The size of the wind farm, whether we are talking of a small-scale cluster of wind turbines up to 20 MW or are farms of up to 100 MW, in itself has limited impact on the time for project delivery. However, it might be easier to site smaller projects at locations where environmental and legal approval conditions are more favourable.

**P7: Requirements for logistics and transportation infrastructure (Q)**

The transportation of onshore wind turbines requires special vehicles, equipment, and routes. The logistics and transportation infrastructure in Ukraine may pose some challenges for renewable energy development due to poor road conditions in some areas, damages to ports and cranes, and security risks in war areas. Transportation through Poland is feasible by road but challenging due to expensive and oversized components. However, when one gets closer to Central Ukraine, the issue becomes more complicated. There is an example of a company that, during the war, managed to transport all the wind turbines through Poland.

The ports have been heavily damaged, and shipments that used to come through Denmark and Germany via the Black Sea have become nearly impossible.

Ensuring access to adequate transport infrastructure may be a critical parameter in the process of identifying sites for wind farms.

Communication infrastructure (preferably through optical fibres) is required to control the wind turbines from a distance.

**P8: Technical installation time (min time after clearance) (Q)**

Less than one year. If experienced construction companies are present, a wind farm (20-100 MW) may be constructed within a time horizon of 6 months.

**P9: Requirements for skilled staff in construction phase (Q)**

The construction of renewable energy projects such as onshore wind farms requires skilled staff in various fields, such as engineering, project management, procurement, installation, commissioning, quality control, health and safety, and environmental protection. Based on the previous experience of erecting about 1.17 GW of wind capacity, it is expected that skilled staff will be available. Three wind farms have been constructed in Ukraine during the war.

Before the war, steel for the towers could be produced in Mariupol but this is obviously no longer an option, and therefore these components have to sources from elsewhere, for example Turkey, Poland, or other countries.

**P10: Grid balancing capacity (R)**

The integration of renewable energy sources such as onshore wind power into the electricity grid requires adequate transmission and distribution lines, substations, balancing and ancillary services, and smart grid technologies. The electricity grid infrastructure in Ukraine has been facing attacks on its electricity infrastructure by missiles and drones from Russia during the war. According to Ukrenergo, wind turbines are comparatively easy to integrate into the electricity grid because turbines are scattered across Ukraine and typically produce for several days in a row.

Wind turbines may contribute to the security of supply at regional level during situations with widespread power outages when critical transmission infrastructure and/or power plants are down. During December 2022, when there was a blackout, part of the Odesa region had electricity thanks to the work of three wind power stations.

In some regions there is an electricity surplus, i.e., despite the war, there is more electrical capacity than required. Therefore, the state of the electricity grid should be factored in as a criterion in the localization of new wind farms.

**P11: Requirements for electricity grid infrastructure (R)**

The electricity grid is considered robust enough to accommodate the integration of onshore wind power, and there is ample wind sites located at a reasonable distance from the grid. This ensures that wind projects should not encounter excessive challenges in connecting to the grid.

**P12: Requirements for skilled staff for operation and maintenance and for special spare parts (R)**

The operation and maintenance of renewable energy projects such as onshore wind farms require skilled staff in various fields, such as monitoring, troubleshooting, repair, inspection testing cleaning optimization, etc. The availability of skilled staff in Ukraine may be limited by factors such as a lack of training programs or migration of qualified workers. Based on the previous experience of erecting about 1.7 GW of wind capacity it is expected that skilled staff will be available. Ukrainian Wind Energy Association hosts two service companies, Firewind and Enerproof.

**P13: Possibility for camouflage and sheltering (R)**

It is not possible to camouflage or shelter individual onshore wind turbines due to their size, but it is possible to protect critical components such as transformer stations with fences and/or by establishing them underground in bunkers or by protecting them with concrete roofs.

The map below shows the potential ranges of Russia artillery and close-range ballistic missiles (CRBM). It appears that a large part of Ukraine, with the exception of the central and southeastern parts, is within the range of CRBMs, and even in these areas, energy infrastructure could potentially be struck by drones or longer-range missiles. The map also shows that the regions in central Ukraine, which are at least at risk of being hit by Russian artillery or missiles, demonstrate a high electricity generation potential during wintertime.

The risk associated with operation almost entirely relate to the risk of Russian attacks on the facilities. Due to the dispersed nature of the energy assets, these risks are deemed to be fairly low, also considering that until now only about 10 wind turbines have suffered damage from the war. Transformer stations demonstrate good opportunities for protection through sheltering and camouflage.

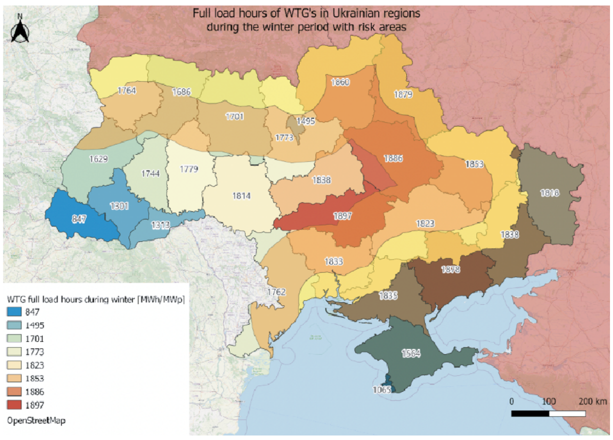



*Figure 18: Expected wintertime wind turbine generation (MWh per MW installed capacity) in different regions of Ukraine during wintertime (which in this context is defined as October-March, 4 374 hours in total) along with an indication of the range of Russian artillery and close-range ballistic missiles.*

**P14: Risk associated with fuel supply (R)**

Not a relevant risk for wind turbines.

**P15: Restoration time**

The restoration time for wind turbines is classified as medium. Depending on the extent of the damage, turbines can be repaired efficiently with the right equipment and skilled technicians. Spare parts are typically delivered relatively quickly. In cases where a new wind turbine is required, much of the planning process can be bypassed, speeding up the restoration process.

#### 4.4.1.4. Additional technology-specific insights from the interviews

Foreign investors such as IBRD (The International Bank for Reconstruction and Development (IBRD) and IFC (International Finance Cooperation) have stated that they are willing to invest during the war, but with one condition. They will invest and provide loans exclusively to foreign companies because it is easier to insure any risks with foreign companies. Moreover, they expect support from the Ukrainian government in developing the projects, along with an insurance fund that would cover military risks.

Foreign renewable energy developers have suggested that fast development of wind turbine farms could be ensured if the state provided sites and building permits for them through expropriation or voluntary agreements with landowners.

The Ukrainian Wind Energy Association asserts that the policy of the National Energy and Utilities Regulatory Commission (NEURC), especially regarding making all RES producers with a capacity of >1 MW responsibility for their imbalances, could be seen as a hindering for the development of not only the wind sector but also solar energy.

### 4.4.2. Household wind turbines

#### 4.4.2.1. Brief technology description

Household wind turbines typically have an installed capacity of between 0.5 and 50 kW, with a rotor swept area smaller than or equal to 200 $m^2$ and max. height of 25 m, generating electricity at a voltage below 1 000 V AC or 1 500 V DC.

Household wind turbines are commonly cited close to buildings in residential areas. By Ukrainian law, it is allowed to install household wind turbines with a capacity of up to 50 kW[19] in private households. To properly place household wind turbines, it is important to maintain a suitable distance from the nearest neighbour. Small wind turbines can generate significant noise due to their fast rotations and high operational speed.

The capacity factor of small wind turbines varies a lot depending on the local conditions. Household wind turbines are often located closer to buildings and trees compared to large wind turbines, which will reduce the annual production from the wind turbines because of turbulence from buildings and trees. The specific output power is, as with the larger turbines, impacted by the capacity factor and the hub height. Household wind turbines can use generated electricity for in-house consumption, in addition to supplying power to the utility grid.

19 https://saee.gov.ua/sites/default/files/EI_wind_en_0.pdf

An analysis of micro and mini wind turbines shows that other technologies are more economically feasible, and it would therefore not be the preferred solution from a purely economic perspective.

*Figure 19: ANTARIS 2.5 kW household wind turbines*

## 4.4.2.2. Criteria evaluation of household wind turbines

**Household wind turbines (<100 kW)**

*Table 22: Wind Power – criteria evaluation matrix for Household wind turbines*

| Criteria evaluation | 3.c. Wind household turbines (<100 kW) |
|---|---|
| Winter impact | WW |
| Implementing speed | QQQ |
| Resilience | RRR |
| Cost (LCOE, wintertime 2 years lifetime) | C |
| General score (1-3) | 1.9 |
| General scores (excl. cost) (1-3) | 2.4 |

**Winter impact (production at wintertime)**

Household wind turbines will be able to provide electricity to individual households and the power system during wintertime. The production depends on the weather patterns; according to analysed data for Ukraine, 51% of the full load hours occurred during the cold period (see Figure 17), indicating that the wind turbines maintain a relatively steady level of electricity generation all year around.

**Implementing speed**

The overall process is estimated to take approximately four to five months from the initial planning stages to the commissioning of the household wind turbine in Ukraine.

Planning and building a household wind turbine in Ukraine involves a relatively shorter and less complex regulatory process compared to larger onshore turbines. Delivery of components is expected to be the most time-consuming activity and is estimated to take approximately three months.

Once on-site, the technical installation time takes about 1-2 months, involving heavy machinery like excavators and cranes. After laying foundations, a waiting period of 2-6 weeks is necessary for the concrete base to cure. The actual installation process, including assembling the tower, generator, blade, and control panel, takes up to 2 days. Skilled staff from a specialized company are required for the installation and commissioning phases.

Some very small wind turbines <10kW are designed to be installed on buildings – this then won't require the time for laying foundations that will shorten the installation time significantly (by 2-6 weeks).

**Resilience**

A household wind turbine might be considered less likely to be a target for potential threats, such as Russian strikes, given its smaller size. Similar to rooftop PVs, these turbines offer advantages in terms of location and distribution. Placed near the demand points, they reduce reliance on the transmission grid, thus lowering the risks associated with potential power capacity loss. Furthermore, localized power generation at the user's site reduces the need for extensive electricity transmission, contributing to enhanced energy security.

**Generation costs (LCOE), short term and over the lifetime**

Over two winters, from an emergency perspective, the LCOE for a household wind turbine amounts to approximately €2 600/MWh, notably higher than larger onshore wind turbines but comparable to residential rooftop PVs. Looking at the lifetime perspective (20 years), LCOE of around €170/MWh of household wind turbines is considered **medium-heigh** compared to the alternatives investigated in this technology catalogue.

## 4.4.2.3. Parameter evaluation household wind turbines

In summary, household wind turbines in Ukraine offer steady electricity generation, with advantages in distribution and regulatory processes. Their smaller size may also enhance resilience to potential threats. The LCOE over two winters is around €2 800/MWh, which is more than three times the cost per MWh compared to larger onshore wind turbines but comparable to residential rooftop PVs. Over the lifetime, household wind turbines demonstrate a LCOE of around €180/MWh.

*Table 23: Wind Power – parameters evaluation matrix for onshore household turbines (kW scale). The LCOE unit is [€//MWh]*

| Parameters | 3.c. Wind household turbines (<100 kW) |
|---|---|
| P1-Electricity production at wintertime | 50% |
| P2-Levelized Cost of Electricity (LCOE) short lifetime, winter production [€/MWh] | 2 628 |
| P3-Levelized Cost of Electricity (LCOE) over lifetime [€/MWh] | 167 |
| P4-Distributed generation | Good |
| P5-Regulation requirement in the project development process | Quick and easy |
| P6-Delivery time and availability of components and materials | Quick and easy |
| P7-Requirements for logistics and transportation infrastructure | Low |
| P8-Technical installation time (after clearance) | Quick and easy |
| P9-Requirements for skilled staff in construction phase | Medium |
| P10-Grid balancing capacity | Medium |
| P11-Requirements for electricity grid infrastructure | Easy |

| | |
|---|---|
| P12-Requirements for skilled staff for operation and maintenance and for special spare parts | Low |
| P13-Possibility for camouflage and sheltering | High |
| P14-Risk associated with fuel supply | Low risk |
| P15-Restoration time | Quick and easy |

**P1: Electricity production in wintertime (W)**

According to analysed data for Ukraine, 51% of the full load hours occurred during the cold period (see Figure 17). Indicating that the wind turbines maintain a relatively steady level of electricity generation, regardless of the season.

**P2: Levelized Cost of Electricity (LCOE) short lifetime, winter production (C)**

The Levelized Cost of Electricity generation over two winters (emergency perspective) amounts to about €2 800/MWh for a household wind turbine. This is significantly higher than for larger onshore wind turbines. The cost is approx. at the same level as residential rooftop PVs.

**P3: Levelized Cost of Electricity (LCOE) over lifetime (C)**

Household wind turbines demonstrate medium LCOEs of around €180/MWh over the lifetime of the turbines that is minimum 20 years in absence of unexpected events.

**P4: Distributed generation (R)**

Household wind turbines have similar benefits, regarding location and distribution, as rooftop PVs. The installations, located near demand, offer the advantage of reducing dependence on the transmission grid, thereby mitigating the risks associated with potential power production capacity loss. Moreover, local power generation at the end-user's site diminishes the necessity for extensive electricity transmission, consequently bolstering energy security.

**P5: Regulation requirement in the project development process (Q)**

It is worth noting that the regulatory process for household wind turbines is often shorter and less complex than that of larger onshore wind turbines. In Ukraine, it is also easier to get permission to set up used household wind turbines, as they do not have to undergo the same lengthy project development process as larger wind turbines.

**P6: Delivery time/availability of components and materials (Q)**

The delivery time for a household wind turbine in Ukraine is estimated to be approx. three months. Before the war, steel for the towers could be produced in Mariupol, but this is no longer an option, and therefore these components have to sources from elsewhere, for example Turkey, Poland, or other countries.

**P7: Requirements for logistics and transportation infrastructure (Q)**

It is important that there is good access to the installation site for a truck, i.e., a wide road with sufficient load bearing capacity.

**P8: Technical installation time (min time after clearance) (Q)**

The technical installation time for a household wind turbine is approx. 1-2 months. The installation process for a wind turbine system may require the use of heavy machinery such as an excavator and crane, depending on the size and type of the turbine. Additionally, it is typically necessary to wait for 2-6 weeks after the laying of foundations to allow the concrete base to cure. After the base is cured, the windmill is erected. The tower, generator, blade, and control panel are delivered and assembled, and the mill is commissioned. The installation work can take up to 2 days.

**P9: Requirements for skilled staff in construction phase (Q)**

To install a household wind turbine a specialized company is required to perform the installation and commissioning.

**P10: Grid balancing capacity (/demands) (R)**

Household wind turbines can, in the same way as larger wind turbines, be used for downregulation, where wind turbines are switched off when there is a surplus of electricity in the electricity grid and a need for downward regulation. If weather conditions permit energy production, wind turbines from a downregulated state can be relatively easily brought back to an upregulated state.

Wind turbines may also contribute to the security of supply during situations with widespread power outages when critical transmission infrastructure and/or power plants are down.

**P11: Requirements for electricity grid infrastructure (R)**

The electricity grid is considered robust enough to accommodate the integration of the amount of energy supplied by household wind turbines.

**P12: Requirements for skilled staff for operation and maintenance and for special spare parts (R)**

Regular servicing, repair and maintenance of all wind turbines are essential to prevent any potential hazards to the safety and well-being of both humans and animals. Wind turbine servicing must be conducted by an authorized or certified service provider.

**P13: Possibility for camouflage and sheltering (R)**

It is not possible to camouflage or shelter individual onshore wind turbines due to their size, but it is possible to protect critical components such as transformer stations with fences and/or by establishing them underground in bunkers or by protecting them with concrete roofs. A household wind turbine might be considered less likely to be a target for potential threats, such as Russian strikes, given its smaller size.

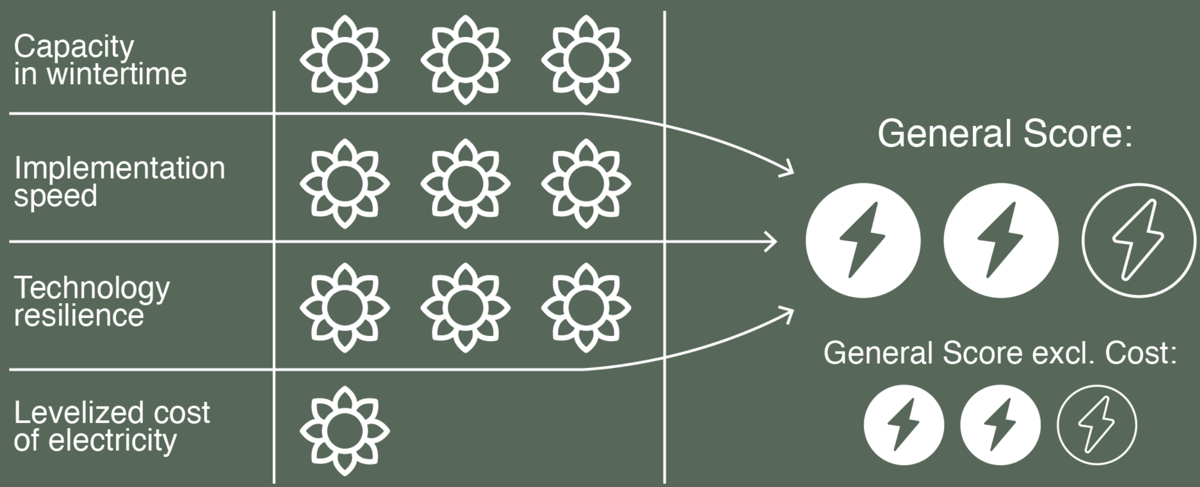
**P14: Risk associated with fuel supply (R)**

Not a relevant risk for wind turbines.

**P15: Restoration time**

The restoration time for wind turbines is classified as **medium**. Depending on the extent of the damage, turbines can be repaired efficiently with the right equipment and skilled technicians. Spare parts are typically delivered relatively quickly. In cases where a new wind turbine is required, much of the planning process can be bypassed, speeding up the restoration process.

# BATTERIES:



Capacity in wintertime
Implementation speed
Technology resilience
Levelized cost of electricity
General Score:
General Score excl. Cost:

# 4.5. Batteries

The rating on the front page shows the score for the technology achieving the highest general score among the sub technologies evaluated in the chapter. The more icons, the better performance[20]. For Li-ion batteries, it is the “Li-ion batteries community scale” that achieve the best score. The scores for all sub-technologies are shown in the table below.

*Table 24: Batteries – Overall criteria evaluation matrix*

| Criteria evaluation | 5.a. Bat, Li-ion utility scale | 5.b. Bat, Li-ion community scale |
|---|---|---|
| Winter impact | WWW | WWW |
| Implementing speed | QQ | QQQ |
| Resilience | RR | RRR |
| Cost (LCOE, wintertime 2 years lifetime) | C | C |
| General score (1-3) | 1.9 | 2.0 |
| General scores (excl. cost) (1-3) | 2.4 | 2.6 |

This chapter covers Lithium-ion batteries (LIB) of two different sizes:

- Grid-scale batteries, (capacity app. 1-150 MW, energy storage 2-500 MWh)
- Community batteries (capacity app. 40-1 000 kW, energy storage 40-2 000kWh)

With increasing shares of renewable energy in power systems, the role of electricity storage grows in importance. Batteries could also be relevant as distributed electricity storage in places, especially where there is no access to the existing pumped hydro storages[21]. The demand could be covered to some extent by pumped hydro storage that is already available in Ukraine.

Furthermore, batteries have experienced notable cost declines in the past years. This is especially true for certain LIB types. Lithium-ion batteries (LIB) have completely dominated the market for grid scale energy storage solutions in the last 6-9 years and appear to be the dominating battery solution. For this reason, this chapter focuses on LIB.

**Brief technology description**

A typical LIB installed nowadays has a graphitic anode, a lithium metal oxide cathode, and an electrolyte that can be either liquid or in (semi-) solid-state. LIB commonly comes in packs of cylindrical cells and can reach energy densities of up to 300 Wh/kg. The battery required an area around 5 $m^2$/MWh.

The potential applications of batteries in electricity systems are very broad, ranging from supporting weak distribution grids, e.g., with frequency regulation and black-starting to the provision of bulk energy services or off-grid solutions.

20 See detailed explanation in Table 2: Overview of the parameters contributing to each criterion, along with the corresponding ratings. The number of icons represents the quality of the rating, with more icons indicating a better rating.

21 e.g., hydro power with dams, including the facility to pump hydro from lower to higher reservoirs

To understand the services batteries can provide to the grid, Rocky Mountain Institute performed a meta-study of existing estimates of grid and customer values by reviewing six sources from across academia and industry. The study's results illustrated that energy storage can provide a suite of thirteen general services to the electricity system (see Figure 20). These services and the value they create generally flow to one of three stakeholder groups: customers, utilities, or independent system operators/regional transmission organizations (ISO/RTOs).

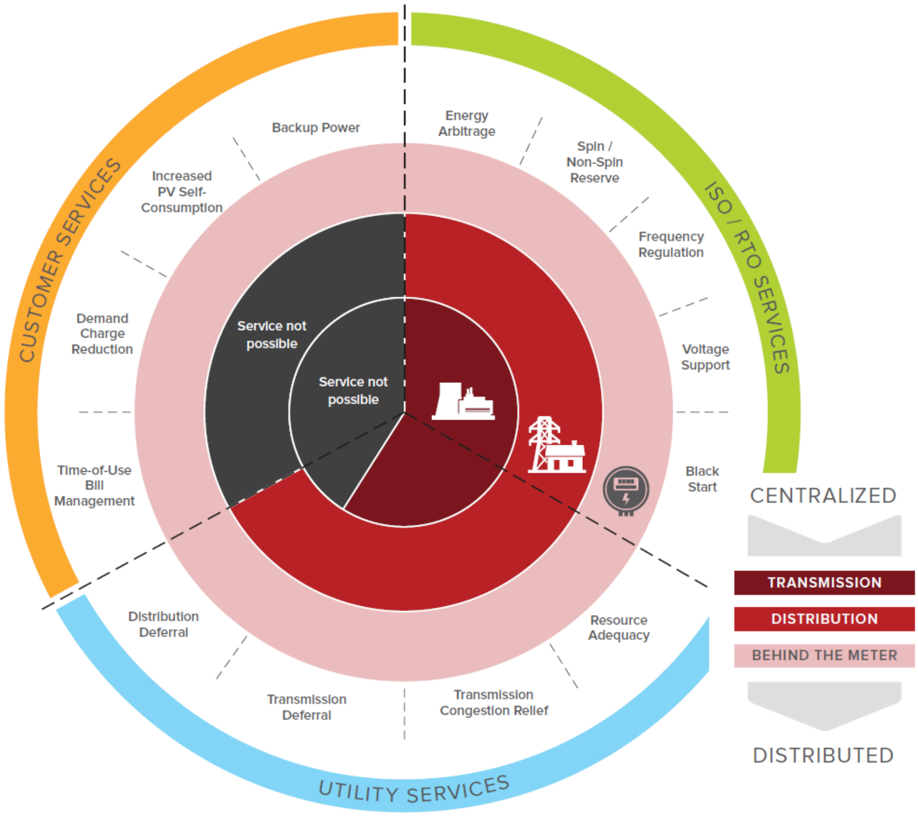



*Figure 20: Services LIB can provide to different stakeholder groups*

This technology description focuses on batteries for the provision of bulk energy services and customer energy management services, i.e., time-shift over several hours (arbitrage) – for example, moving PV generation from day to night hours – the delivery of peak power capacity, demand-side management, and power reliability and quality.

In order to fully capitalize on the benefits of LIB storage in the grid, the implementation of dispatching strategies with frequent intervals such as hourly or 15-minutes planning is recommended to get the full benefit of the batteries.

Charging and discharging rates of LIB are often measured with the C-rate, which is the maximum capacity the battery can deliver relative to its energy volume. For example, if a battery can be fully discharged in 20 minutes, 1 hour, or 2 hours, then it has C-rates of 3C, C, or C/2, respectively. Operations at higher C-rates than specified in the battery pack could be possible but would lead to a faster degradation of the cell materials. LIB do not suffer from the memory effect issue (the effect of batteries gradually losing their maximum energy capacity if they are repeatedly recharged after being only partially discharged) and can be used for variable depths of discharge at short cycles without losing capacity. The relationship between battery volume (in MWh) and loading/unloading capacity (in MW) can be customized based on the system needs and to obtain a better business case.

The lifetime of battery energy technologies is measured by the total number of cycles undergone over the lifetime. Nowadays, the best Li-ion batteries typically endure a lifetime of around 10 000 to 15 000 cycles at a depth of discharge (DoD) of 60-80%.

It is expected that the batteries will be charged with electricity produced by nuclear power plants, as these types of power plants provide a consistent baseload, which, during the emergency in Ukraine, enables the batteries to be charged at low demand periods and then discharged at periods where the demand is higher or in case of fallouts. Furthermore, at the present time, photovoltaics and wind turbines are not as prevalent in Ukraine's electricity system, leaving the majority of the electricity to be available through nuclear power plants. As a result of this assumption, the charging price is expected to resemble the fuel price for the nuclear power plant as well as the round-trip efficiency of the battery. Alternatively, to use the batteries for emergency response and peak shaving. Batteries can during peace time be charged when the power prices are low and discharged when the power prices are high, changing the use and business case of the batteries. Additionally, the batteries can be used for capacity remuneration on the ancillary services market. Furthermore, the batteries can be used in conjunction with photovoltaics or wind turbines to move the electricity dispatch to more profitable hours, when the cannibalization is reduced and thereby the prices increase. To account for these two separate ways of calculating the charging price, the charging price for the full-life time of the batteries will be calculated by using the nuclear fuel price and round trip efficiency for the first 5 years and a quarter of the nuclear price for the remaining 15 years, and it is assumed that the RE prices will be lower than the nuclear prices.

## 4.5.1. Grid-scale batteries

### 4.5.1.1. Brief technology description

Grid-scale batteries are a type of energy storage technology that can store large amounts of electricity for later use. They can help balance the supply and demand of electricity, especially when there is a high penetration of renewable energy sources, such as wind and solar, that are variable and intermittent. Grid-scale batteries can also provide other benefits to the power system, such as frequency regulation, voltage support, peak shaving, and black start capability.

A schematic overview of a battery system and its grid connection can be seen in Figure 21. A Thermal Management System (TMS) controls the temperature in the battery packs to prevent overheating and thermal runaway. The Energy Management System regulates energy exchange with the grid. Power electronics (inverters) convert DC into AC before power is injected into the grid. In some cases (high-voltage grids), a transformer might be required to feed electricity into the grid.

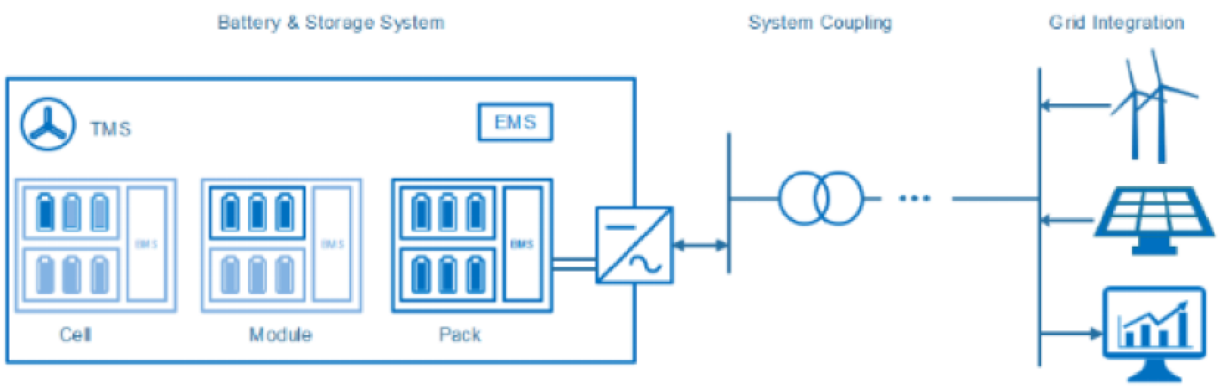



*Figure 21: Schematic illustration of a grid-scale battery storage system*

### 4.5.1.2. Criteria evaluation for LIB utility scale

*Table 25: LIB utility scale – criteria evaluation matrix*

| Criteria evaluation | 5.a. Bat, Li-ion utility scale |
|---|---|
| Winter impact | WWW |
| Implementing speed | QQ |
| Resilience | RR |
| Cost (LCOE, wintertime 2 years lifetime) | C |
| General score (1-3) | 1.9 |
| General scores (excl. cost) (1-3) | 2.4 |

**Winter impact (production at wintertime)**

LIBs are suitable for electricity storage in all seasons of the year. In systems with variable renewable energy (VRE) sources, LIBs are an efficient technology for ensuring stability because they can deliver full power within seconds. However, the effectiveness of batteries diminishes in colder temperatures, particularly below 0°C. And batteries can have trouble starting the charging or discharging in colder temperatures. Furthermore, LiBs are not suitable for storing over longer time periods, e.g., over more weeks, because the level of self-discharging is relatively high, thereby not suitable for seasonal shifts of energy production because of a relatively high rate of self-discharging and the high cost of the storage part.

**Implementing speed**

The implementation speed of batteries in Ukraine is influenced by several factors, such as the delivery time, the technical installation time, the logistics, and the knowledge requirements. The delivery time of batteries is a minimum of six months. For very large systems (100 MW) the delivery time may extend up to 1-2 years. The logistics of transporting batteries to Ukraine can be challenging, as suppliers only delivers to Poland or Romania, and the buyer must plan the transportation from there to Ukraine. However, batteries are optimized for transportation – they are heavy but optimized in containers.

The technical installation time of batteries in Ukraine is about 13 weeks, depending on the complexity of accessing the electrical system. The installation time also depends on the functions of the battery, e.g., if it needs to be able to restart the system in case of a blackout. The implementation of batteries in Ukraine requires an electrical engineer.

Altogether, this results in an implementation period of more than a year for systems of approx. 20 MW. Larger systems are expected to have a longer delivery time, increasing the implementation time.

**Resilience**

The use of battery systems is effective for ensuring stability in power supply. In situations where the electricity grid or electricity production is damaged, batteries can briefly function as a backup as they can deliver their full effect within a few seconds. However, in the context of war, batteries, like other energy infrastructure, face vulnerability. Unlike wind turbines, large scale batteries are easier targets since they are one unit of a relatively large size.

The compact nature of batteries does however also mean that they potentially can be camouflaged or protected by layers of concrete.

**Generation costs (LCOE), short term and over the lifetime**

Over a two-year span, considering an emergency scenario, the Levelized Cost of Electricity (LCOE) for batteries is projected to be €2 025/MWh, presenting a comparatively higher figure than several technologies, but a lower cost than, e.g., solar PVs.

Examining the lifetime perspective, the LCOE of €264/MWh for batteries is regarded as notably high when contrasted with the array of alternatives explored in this technology catalogue.

While battery costs have fallen dramatically in recent years due to the scaling up of electric vehicle production, market disruptions and competition from electric vehicle makers have led to rising costs for key minerals used in battery production, notably lithium. It is now becoming evident that further cost reductions rely not just on technological innovation but also on the prices of battery minerals.

## 4.5.2. Community batteries

### 4.5.2.1. Brief technology description

A community battery is a shared energy storage system that stores excess energy generated from local renewable sources, like solar panels; it allows both that neighbourhood and the wider community to access the multiple benefits batteries can provide. It typically includes a large battery unit, an inverter, and a management system. The setup involves connecting the battery to the local grid, allowing it to store and distribute energy as needed. This helps stabilize the grid, reduce energy costs, and enhance the use of renewable energy within the community.

Battery energy storage systems can have manifold applications and thus can be installed at different scales and voltage levels (see Figure 21). BESS architecture is ultimately shared across use types, with minor differences depending on the single applications. In off-grid and micro-grid contexts, grid connection costs are reduced totally or partially.

Community batteries can be installed in two main configurations: in front of the meter and behind the meter. In this context we only consider the in-front-of-the-meter configuration, while when installed on the individual prosumer`s side, it is seen as a home battery, not providing the same benefits for the community / distribution grid.

When installed in front of the meter, these batteries are connected directly to the electricity network, outside of individual homes or properties. They act as a central storage unit for the community, storing excess energy generated from local renewable sources like rooftop solar panels. This energy can then be distributed back to the grid during peak demand times. This setup helps stabilize the grid, reduces energy costs, and maximizes the use of renewable energy. It also supports grid reliability and can provide backup power during outages.

Industry and households can install batteries behind the meter to reshape the own load curve and to integrate distributed generation such as rooftop or industrial PV. The major benefits of this setup are greater energy independence, potential cost savings on electricity bills, and enhanced energy security for the individual consumer are related to retail tariff savings, peak tariff reduction, reliability, and quality of supply.

Batteries can boost the self-consumption of electricity and back up the local grid by avoiding overload and by deferring new investments and reinforcements. In case of bi-directional flows to/from the grid (prosumers).

BESS can increase the power quality of distributed generation and contribute to voltage stability. In developed market settings, these functions might not only reflect the requirements enforced by the regulation but also materialize in remunerated system services.

## 4.5.2.2. Criteria evaluation for community scale LIB

*Table 26: LIB community scale – criteria evaluation for community scale LIB*

| Criteria evaluation | 5.b. Bat, Li-ion community scale |
|---|---|
| Winter impact | WWW |
| Implementing speed | QQQ |
| Resilience | RRR |
| Cost (LCOE, wintertime 2 years lifetime) | C |
| General score (1-3) | 2.0 |
| General scores (excl. cost) (1-3) | 2.6 |

**Winter impact (production at wintertime)**

Batteries are suitable for electricity storage in all seasons of the year. However, the effectiveness of batteries diminishes in colder temperatures, particularly below 0°C. And batteries can have trouble starting charging or discharging in colder temperatures. Furthermore, LiBs are not suitable for storing over longer periods, e.g., over more weeks, thereby, not suitable for seasonal shift of energy production because of a relatively high rate of self-discharging and the high cost of the storage part.

**Implementing speed**

Community batteries and other smaller battery systems exhibit greater agility compared to the larger batteries. One notable advantage of community batteries lies in their shorter delivery times compared to larger-scale batteries. The modular design and smaller scale contribute to a more streamlined manufacturing process, allowing for quicker production and dispatch.

**Resilience**

The use of battery systems is effective for ensuring stability in power supply. In situations where the electricity grid or electricity production is damaged, batteries can briefly function as a backup as they can deliver their full effect within a few seconds. In the context of war, batteries, like other energy infrastructure, face vulnerability. Unlike wind turbines, batteries are easier targets since they are one unit of a relatively large size.

The compact nature of batteries does, however, also mean that they potentially can be camouflaged or protected by layers of concrete.

**Generation costs (LCOE), short term and over the lifetime**

Over a two-year span, considering an emergency scenario, the cost of community batteries is estimated to be €2 570/MWh. This is higher than many other technologies, and it is therefore considered fair. Looking at the overall lifetime, the cost of community batteries is €312/MWh.

This is considered high compared to the other options we've explored in this technology catalogue.

## 4.5.3. Parameter evaluation for batteries

*Table 27: Parameters evaluation matrix for batteries. The LCOE unit is [€//MWh]*

| Parameters | 5.a. Bat, Li-ion utility scale | 5.b. Bat, Li-ion community scale |
|---|---|---|
| P1-Electricity production at wintertime | >75% | >75% |
| P2-Levelized Cost of Electricity (LCOE) short lifetime, winter production [€/MWh] | 2 967 | 2 549 |
| P3-Levelized Cost of Electricity (LCOE) over lifetime [€/MWh] | 155 | 261 |
| P4-Distributed generation | Medium | Good |
| P5-Regulation requirement in the project development process | In between | In between |
| P6-Delivery time and availability of components and materials | In between | In between |
| P7-Requirements for logistics and transportation infrastructure | Low | Low |
| P8-Technical installation time (after clearance) | Quick and easy | Quick and easy |
| P9-Requirements for skilled staff in construction phase | Low | Low |
| P10-Grid balancing capacity | High | High |
| P11-Requirements for electricity grid infrastructure | Easy | Easy |
| P12-Requirements for skilled staff for operation and maintenance and for special spare parts | Low | Low |
| P13-Possibility for camouflage and sheltering | Medium | Medium |
| P14-Risk associated with fuel supply | Medium risk | Medium risk |
| P15-Restoration time | Quick and easy | Quick and easy |

**P1: Electricity production at wintertime (W)**

Batteries, while versatile for electricity storage throughout the year, experience diminished effectiveness in colder temperatures, particularly below 0°C, impacting their winter production capabilities. And batteries can have trouble starting charging or discharging in colder temperatures. Furthermore, LiBs are not suitable for storing over longer time periods, e.g., weeks, thereby, not suitable for seasonal shift of energy production because of a relatively high rate of self-discharging and the high cost of the storage part.

**P2: Levelized Cost of Electricity (LCOE) short lifetime, winter production (C)**

Lithium-ion batteries are relatively expensive technologies compared to some production technologies assessed in this technology catalogue, such as solar PVs. The cost of batteries has been on a decreasing trend over the past years due to significant investments in developing efficient batteries for electric vehicles.

**P3: Levelized Cost of Electricity (LCOE) over lifetime (C)**

Over the lifetime, the cost for batteries is comparatively high when compared to alternative technologies explored in this technology catalogue.

**P4: Distributed generation (R)**

The nature of the batteries is modular, and both grid-scale batteries and community batteries come in sizes below 5 MW. Additionally, batteries can be placed very close to consumers.

Therefore, both types of batteries are rated good.

Furthermore, batteries contribute to distributed generation, offering localized power storage and distribution capabilities. Batteries and especially community batteries play a crucial role in stabilizing smaller grids or microgrids by balancing supply and demand. By providing voltage and frequency regulation, community batteries help maintain the stability of smaller grids, ensuring a reliable and consistent power supply.

**P5: Regulation requirement in the project development process (Q)**

The regulatory aspects in the development process for battery projects need to consider optimal integration within the energy landscape. For the time being, UA is missing legislation on connecting batteries at the system level.

**P6: Delivery time/availability of components and materials (Q)**

Delivery times for grid-scale batteries range from a minimum of six months to 1-2 years for very large systems, affecting implementation speed. Community batteries generally have shorter delivery times.

**P7: Requirements for logistics and transportation infrastructure (Q)**

The containerized design of batteries facilitates transportation to Ukraine using trucks, streamlining logistics.

**P8: Technical installation time (min time after clearance) (Q)**

The technical installation time for batteries in Ukraine is approximately 2-3 weeks, contingent on factors like access to the electrical system and specific functionalities.

**P9: Requirements for skilled staff in construction phase (Q)**

Implementing batteries during the construction phase in Ukraine necessitates skilled staff, particularly electrical engineers.

**P10: Grid balancing capacity (/demands) (R)**

Batteries contribute to grid balancing of capacity and demands, enhancing stability in power supply. Batteries and especially community batteries can play a crucial role in stabilizing smaller grids or microgrids by balancing supply and demand. By providing voltage and frequency regulation, community batteries help maintain the stability of grids.

**P11: Requirements for electricity grid infrastructure (R)**

The use of batteries requires careful consideration of electricity grid infrastructure requirements to ensure compatibility and optimal performance.

**P12: Requirements for skilled staff for operation and maintenance and for special spare parts (R)**

The operation and maintenance of batteries in Ukraine demand skilled staff, affecting long-term resilience. Additionally, the need for special spare parts adds complexity to the maintenance process.

**P13: Possibility for camouflage and sheltering (R)**

Batteries can potentially be camouflaged or sheltered. Community batteries, being smaller, may be considered less likely targets for potential threats.

**P14: Risk associated with fuel supply (R)**

Unlike some other energy sources, batteries are not subject to risks associated with fuel supply, contributing to their reliability.

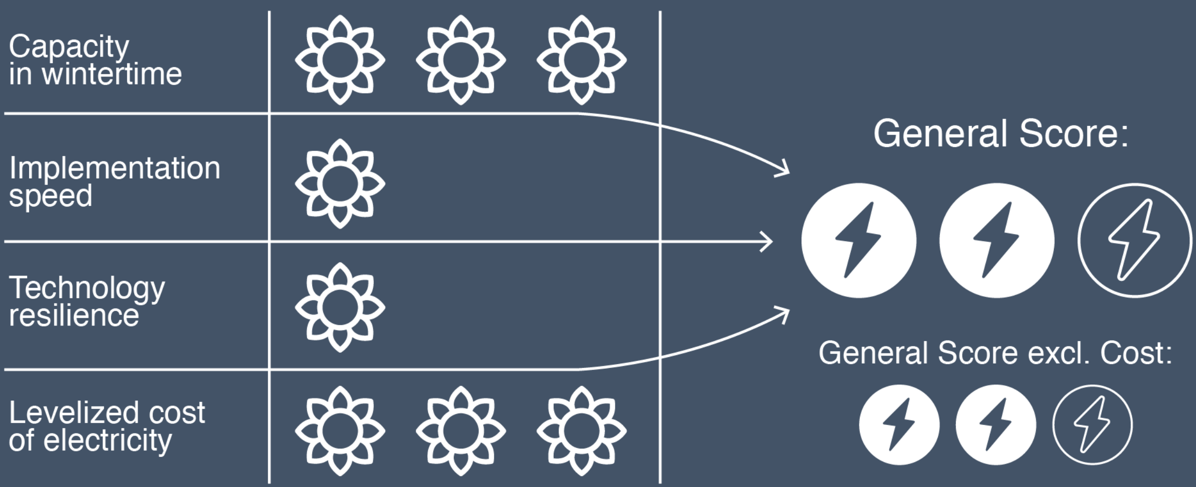
**P15: Restoration time**

The restoration time for large battery systems is assessed to be quick and straightforward. Their modular design allows for the easy replacement of individual components, such as battery modules or inverters, without the need for extensive downtime. Repairs typically require less specialized equipment and personnel compared to other energy systems. Additionally, the compact and standardized nature of large battery installations enable efficient maintenance and faster recovery.

## 4.5.3.1. Data sheet

In Appendix F.

# COAL POWER PLANT LIFETIME EXTENSION



# 4.6. Coal power plants, repair, and lifetime extension

The rating on the front page shows the score for the lifetime extension and repair of coal power plants. The more icons, the better performance[22].

*Table 28: Coal power – overall criteria evaluation matrix*

| Criteria evaluation | 4. Coal retrofitting |
|---|---|
| Winter impact | WWW |
| Implementing speed | Q |
| Resilience | R |
| Cost (LCOE, wintertime 2 years lifetime) | CCC |
| General score (1-3) | 2.1 |
| General scores (excl. cost) (1-3) | 1.9 |

This chapter covers the possibility of extending the lifetime of coal-based power plants, as well as giving some insights into the proportion of the cost for each component category that a coal-based power plant consists of.

Based on data from the ENTSO-E Transparency platform, the Ukrainian power system had a generation capacity of 18.59 GW from coal-based power plants in 2021. In that year, the power generation from coal-based power plants was 43.51 TWh, making up 29% of Ukraine's total power generation.

The proportion of the cost is reported because, as of 2021, a large part of the power generation capacity in Ukraine consisted of coal-fired power plants, and some of the coal-based power plants might not need a full lifetime extension but a replacement of a single component category. Replacements of the components are necessary, as the Ukrainian energy infrastructure is under constant attack from Russia, which means that some of the coal-fired power plants either are or will be completely or partially destroyed.

## 4.6.1. Brief technology description

A coal-fired power plant works by taking delivery of shipments of coal, through railways, barges, and/or ships, where it is stored in a coal yard. Thereafter, the coal is typically ground to powder for efficient burning and blown into the combustion chamber of a boiler, where water is heated to extremely high temperatures, turning the water into highly pressurized steam. In some coal plants, the coal is fed directly into the combustion chamber without being ground. The steam is led through a turbine that drives the driveshaft connected to the generator, which produces electricity with each revolution of the magnet within the generator. The steam is led to a condenser, with a heat exchanger, which transfers the steam back into hot water that is led into the boiler again. This is done, so that there is no need for a huge temperature change in the water, for it to become steam. The heat exchanger transfers the heat energy to the water in a district heating grid or to cold water sourced from the area, which is led out to the local environment again. As the water passes through a heat exchanger, it does not absorb any of the pollutants of the combustion process, only the heat energy.

22 See detailed explanation in Table 2: Overview of the parameters contributing to each criterion, along with the corresponding ratings. The number of icons represents the quality of the rating, with more icons indicating a better rating.

When a coal power plant has been in operation for a long time (e.g., 25 years or more), the reliability of its components and systems will likely decrease, leading to reduced availability and/or increased O&M costs. Therefore, based on experience, it will usually be necessary and beneficial to carry out a larger package of work that addresses repairs, renovation, and replacement of selected components and systems depending on their actual condition. Often also, improvement of environmental performance may be required, e.g., by improving the flue gas cleaning performance. This 'Lifetime Extension' (LTE) is done with the purpose of restoring the plant to come close to its original condition in terms of availability, efficiency, and O&M costs. The exact scope and extent of such a campaign, though, shall be tailored to the actual plant in question and will depend on its design, previous records of operation, earlier major works carried out, etc. Also, the expected/desired future operation of the plant is considered. Whether or not to extend the life of a power plant is therefore not a simple decision but involves complex economic and technical factors.

It may be convenient to carry out all necessary work in one campaign to reduce the overall downtime. For this case, it is assumed that all work is done in one campaign. It is expected that the original plant will comply with the environmental legislation at the time of the LTE. The costs of bringing it up to date prior to the LTE are therefore not considered. The LTE described here does not take specific measures to increase the efficiency, emissions level standards, or regulation abilities of the plant.

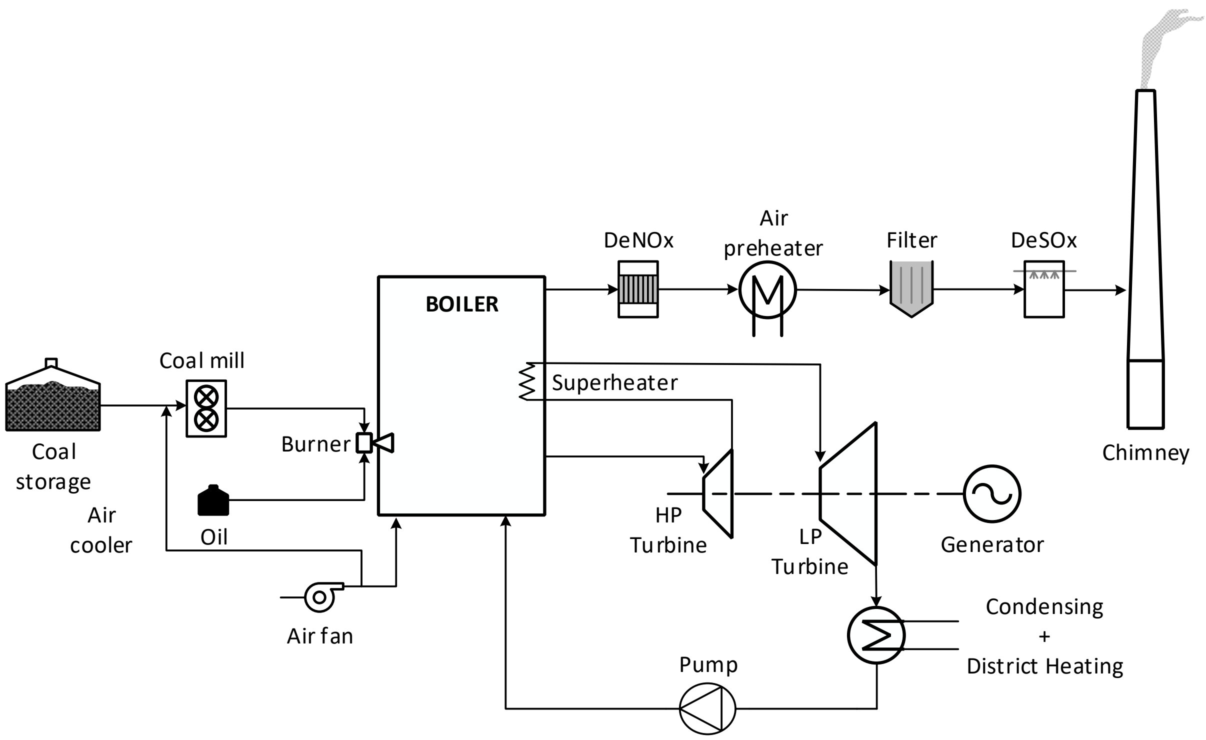



*Figure 22: Sketch of the main elements of a large coal fired CHP plant*

In connection with the LTE, the plant will be out of operation for a period, typically 6-9 months. The cost of the LTE will depend on the scope of the campaign and specific component categories that are to be replaced. These are given as follows:

- Revision of electrical systems
- Instrumentation and control systems replacement
- Pulverizes upgrade or replacement (fuel supply and disposal)
- Boiler upgrade
- Turbine refurbishment (possibly generator refurbishment)

- Water systems (heat exchanges for condensers and district heating)
- Buildings
- Flue gas cleaning

To decide which component categories need to be refurbished and included in the LTE, the plant's condition needs to be investigated to obtain an understanding of its condition. This can be done by using diagnostic systems and making a detailed remaining life assessment. The proportion of the investment cost for the lifetime extension of a coal-fired power plant is given in Figure 23.

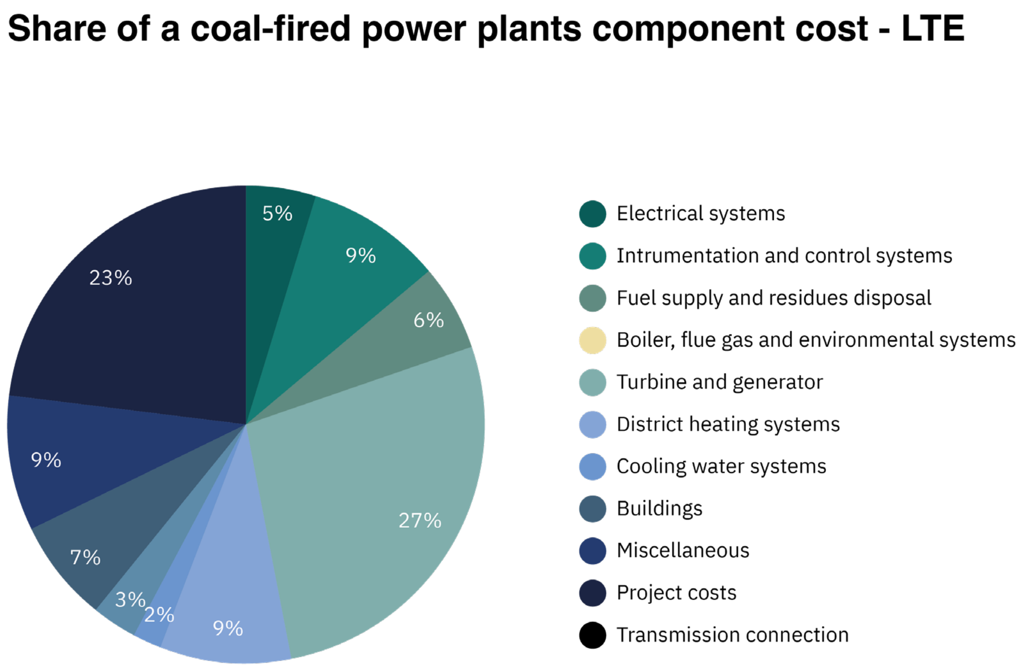



*Figure 23: Illustrates the proportion of the investment cost, when a coal-fired power plant's lifetime is extended*

Sometimes whole parts of the plant need to be replaced, and in the case of Ukraine, the parts of the plant, i.e., the component categories, might have been destroyed by Russian bombardments. The expenditure for the repairs is different from the lifetime extension of the plant, as the components probably need to be fully replaced. The price for the component categories is therefore considered to be similar to the investment cost of a new coal-fired power plant. Figure 24 presents the proportions of investment costs for different component categories within a new coal-fired power plant. This can be used as an indicator for what the expected price of a component category might be, when a coal-fired power plant is repaired.

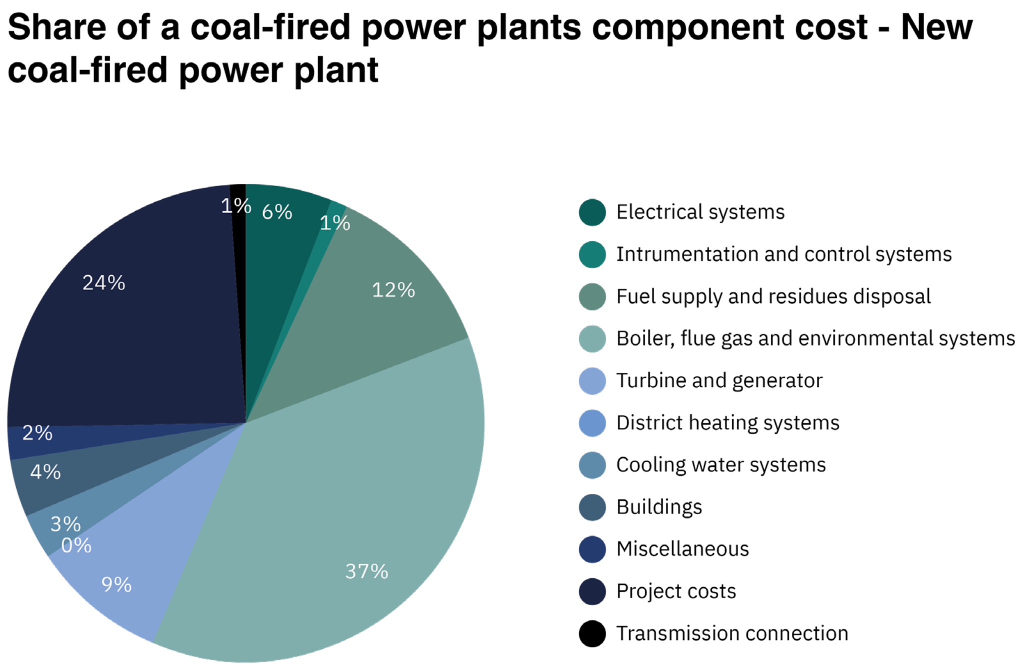



*Figure 24: Illustrates the proportion of the investment cost, when a coal-fired power plant's lifetime is extended*

## 4.6.2. Criteria evaluation coal plants

Coal Power Plants, Lifetime Extension

*Table 29: Coal Power Plants, Lifetime Extension – criteria evaluation matrix*

| Criteria evaluation | 4. Coal retrofitting |
|---|---|
| Winter impact | WWW |
| Implementing speed | Q |
| Resilience | R |
| Cost (LCOE, wintertime 2 years lifetime) | CCC |
| General score (1-3) | 2.1 |
| General scores (excl. cost) (1-3) | 1.9 |

**Winter impact, production at wintertime (W)**

Lifetime extension or repairs of existing Ukrainian coal-fired power plants can significantly contribute to the Ukrainian power system in the winter.

Lifetime extension can have a significant impact, because the refurbishment of the coal-fired power plants can lead to increased output capacities, as the older power plants may have lower production levels than their design parameters, and the refurbishment then raises the plant's production to their normal levels. Furthermore, during the lifetime extension, newer technologies can be implemented that can further increase output levels.

Coal-fired power plants can regulate their generation, allowing them to produce at full capacity during wintertime.

**Implementing speed (Q)**

Even though many of the coal-fired power plants are readily available to receive a lifetime extension or repairs and the refurbishment typically takes 6-9 months, the implementation of the lifetime extension is still expected to take around 1.5 years. This is because on top of the implementation, the components for the plants need to be sourced; there is a planning and training process for the refurbishment of the coal-fired plants.

**Resilience (R)**

The lack of resilience of the lifetime extension of coal-fired power plants is attributed to the high capacity of a single power plant. The capacity of the coal-fired power units in Ukraine ranges between 150 and 325 MW and plants ranges up to 2 300 MW, which means that a large portion of the power generation can be taken out through a single strike on a power plant. Which can happen right after its refurbishment, either through drones, artillery, or missile strikes. Furthermore, due to the size of a coal-fired power plant, it cannot be expected that the whole plant can be bunkered, although some critical parts can be.

The majority of Ukrainian coal, which was used to fire the coal plants, originated from Ukrainian coal mines in the Donbass region. At the present time, this region is either occupied by Russian forces or an active warzone, which means that the coal mines are inaccessible for mining. Therefore, the coal for the power plants needs to be sourced from the international market. The availability of coal has significantly dropped for the Ukrainians, meaning that coal as a fuel is less reliable.

**Generation costs (LCOE), short term and over the lifetime (C)**

Due to the lifetime extension of coal fired power plants, low upfront cost, and great potential for generation during the winter, using lifetime extension as a solution demonstrates to have the lowest generation cost among all the technologies over two winters. In the case of the LCOE over the lifetime, the LTE of a coal-fired power plant is expected to be around medium in comparison to all the other assessed technologies, which means the price is approximately two times higher than onshore wind turbines.

There can be many different forms of repairs needed for a coal-fired power plant, which has been struck via drone strike, missiles, or artillery. Some coal-fired power plants might need to be fully repaired, while others only need small repairs. Therefore, the proportions of the investment cost needed for replacing a component category has been given on Figure 24. In the assessment of the LCOE for a coal-fired power plant that needs to be repaired, it is assumed that the cost for repairing a coal-fired power plant is 30% of the cost of a retrofitted coal-fired power plant. In this case, the LCOE over two winters is still expected to be the second best, right after the LTE of a coal-fired power plant. The LCOE of a repaired (30%) coal-fired power plant over the whole lifetime is expected to lie in the **medium** range, in comparison to the LCOE of the other technologies.

### 4.6.3. Parameter evaluation of coal plants

This section covers the parameter evaluation of coal-fired power plants that was used as the basis for the criteria evaluation.

*Table 30: Coal Power Plants, Lifetime Extension – parameters evaluation matrix. The LCOE unit is [€//MWh]*

| Parameters | 4. Coal retrofitting | 4. Coal repair |
|---|---|---|
| P1-Electricity production at wintertime | >75% | >75% |
| P2-Levelized Cost of Electricity (LCOE) short lifetime, winter production [€/MWh] | 609 | 209 |
| P3-Levelized Cost of Electricity (LCOE) over lifetime [€/MWh] | 146 | 107 |
| P4-Distributed generation | Poor | Poor |
| P5-Regulation requirement in the project development process | In between | In between |
| P6-Delivery time and availability of components and materials | In between | In between |
| P7-Requirements for logistics and transportation infrastructure | Medium | Medium |
| P8-Technical installation time (after clearance) | Lengthy and complicated | Lengthy and complicated |
| P9-Requirements for skilled staff in construction phase | Medium | Medium |
| P10-Grid balancing capacity | Medium | Medium |
| P11-Requirements for electricity grid infrastructure | Moderate | Moderate |
| P12-Requirements for skilled staff for operation and maintenance and for special spare parts | Low | Low |
| P13-Possibility for camouflage and sheltering | Low | Low potential |
| P14-Risk associated with fuel supply | Medium risk | Medium risk |
| P15-Restoration time | In between | In between |

**P1: Electricity production in wintertime (W)**

If there is fuel available, coal fired power plants may operate at their full capacity any hour of the day, except for the planned and forced outages. Depending on the specific power plants, there are different requirements for when the plant should be refurbished, meaning that there will be some weeks of the year when it is planned that the coal plants will be out of operation.

Typically, the refurbishment is planned to be done during the summer, when the need for the plant is greatly lower. Forced outages can happen for multiple reasons, but typically occur due to some form of breakdown that occurs during production.

As mentioned, the need for a coal-fired power plant is lower during the summer. The power consumption is lower. Furthermore, coal-fired power plants also compete amongst each other and against VREs and other power plants.

Due to these reasons, it is assumed that a coal-fired power plant will operate at what equates to full capacity for 5 000 hours during a year, so-called Full Load Hours (FLH). As the majority of the production is likely to happen during the winter period, it is assumed that 75% of the FLH will occur during the wintertime, which means that it is assumed that a coal-fired power plant will operate with 3 750 full load hours during wintertime (86% capacity factor). This corresponds to the annual FLH of a wind turbine located in the Ukrainian region with the best wind profiles and above twice the annual FLH of a PV plant located in the Ukrainian region with the best solar profile. If Ukrainian power plants do not cannibalize on each other, or due to missing capacity caused by Russian bombardments, then the FLH can be expected to be higher. Furthermore, coal-fired power plants are expected to generate power in the intermediate and base load hours, which means that the FLH for coal-fired power plants can be expected to be higher than gas engines and turbines.

**P2: Levelized Cost of Electricity (LCOE) short lifetime, winter production (C)**

In the emergency scenario, where the lifetime extension of the coal-fired power plant is only utilized for two winter periods, the LCOE is in the low end of all the assessed technologies. The LCOE is calculated to be €609/MWh. For the explorative scenario, where the price for repairs is expected to be 30% of the initial investment cost of the lifetime extension, the LCOE is calculated to be €209/MWh – note that the LCOE of the repaired coal-fired power plant is indicative, there are many scenarios regarding the repairs of a bombarded coal-fired power plant.

The lifetime extension and repair of a coal-fired power plant stand out because the majority of the life-time expenditure is caused by CO2 emissions and fuel consumption, whereas the investment cost is relatively low, and so is the cost for operation and maintenance. As less fuel is consumed and the emissions are lower, as the operational period is significantly shorter, the fuel and emissions costs are proportionately lower in comparison to the investment cost, regarding the LCOE.

**P3: Levelized Cost of Electricity (LCOE) over lifetime (C)**

The LCOE over the lifetime extension period of a coal-fired power plant is expected to be approximately €146/MWh. This is around 4 times higher than utility scale solar and wind power, but similar to new gas engines and turbines. The emissions costs make up the vast majority of costs, and therefore, obviously, the generation costs from lifetime-extended coal-fired power plants are highly sensitive to cost of CO2. The projected LCOE assumes a long-term CO2 cost of €54/MWh.

**P4: Distributed generation (R)**

Typically, the power generation capacity of a coal-fired power units in Ukraine ranges between 150 and 325 MW and plants ranges up to 2 300 MW, which means the generation capacity is very centralized.

**P5: Regulation requirement in the project development process (Q)**

The regulation requirement for lifetime extension of coal-fired power plants is expected to be swift and easy, as the plant can be assumed to already hold a license to operate. But the planning process for what to refurbish the plant expects to take time. It is estimated that the planning process will be around 26 weeks, which is rated to be a medium time frame.

**P6: Delivery time / availability of components and materials (Q)**

The delivery time of all components and materials for the refurbishment of a coal-fired power plant is expected to be approximately 26 weeks from the initial purchase date. This is because there is an ongoing supply chain shortage for electrical components, where some of the components take between 26 and 52 weeks to be delivered, but it is expected that during the refurbishment or repairs, only some components are expected to be newly produced, and this varies between each coal plant. So, in general, it is expected to take 26 weeks to source the components for the different coal plants. This is a medium time frame for sourcing components.

If a coal-fired power plant needs to be repaired, due to it being bombarded, the delivery time can vary significantly for the different components that are needed for the repairs. Through the interviews conducted with producers, it was hard to get a clear estimate for when they could deliver specific parts, but the estimates for when they could deliver the entire technological solution was clearer.

If no transformers are available and the transformer for a specific coal-fired power plant has been destroyed, it will take approximately 1 year before a new transformer can be obtained.

**P7: Requirements for logistics and transportation infrastructure (Q)**

This unit and the components needed for construction, as well as the fuel, typically requires transport by equipment of the size of a train or a boat, which requires that the coal-fired power plant is located beside a harbour or railway. But as the coal plants are already built and only need to be refurbished or repaired, it is assumed that the coal plants are already located beside a railway or harbour. This means that the refurbishment or repair of a coal-fired power plant has a medium requirement for logistics and transportation infrastructure, as railways or harbours are already available, but they are still reliant on the transportation infrastructure. But there is probably no need for building new harbours or railways.

**P8: Technical installation time (min time after clearance) (Q)**

When the refurbishment of a coal-fired power plant is initialized, the refurbishment typically takes 26-39 weeks. Considering that the work need be undertaken while the plant is in risk of air attacks from Russia, special precautions may have to be taken and hence the upper level of the interval, i.e., 39 weeks, is considered a realistic time frame for refurbishment. If a coal plant has been struck by Russia, the time to repair the power plant depends heavily on how much has been destroyed. Some repairs will be faster than 26 weeks, but if the majority of the plant is destroyed, the amount of time required for repair works may resemble the construction time for a new plant. 39 weeks is considered to be a lengthy time frame.

**P9: Requirements for skilled staff in construction phase (Q)**

During the construction phase, general labourers, heavy equipment operators, concrete workers, welders, plumbers, electricians, HVAC technicians, and safety specialist workers are required. These labourer types should be available in Ukraine or can be sent from other countries, depending on company policies. If companies cannot send their employees to Ukraine to perform the construction due to security concerns, it is reasonable to assume that some companies can and will educate general labourers from Ukraine. As each coal-fired power plant is different from another and they are not based on modular builds, engineers are needed in some parts of the construction phase to oversee quality control. Furthermore, engineers are needed to adjust building schematics if something in the construction does not work as expected or properly. These are common issues for plants that are tailor made, in comparison to modular build solutions that are well tested. This is why the requirement for skilled staff is considered medium during the construction phase.

According to estimates provided by the Ukrainian partners, Ukraine is short of up to 5 million workers. Which means that during the construction phase, it might be hard to source the number of labourers needed for a large construction project.

**P10: Grid balancing capacity (/demands) (R)**

Assuming coal is available, a lifetime extended or repaired coal-fired power plant can produce electricity at any hour of the day. It takes several hours to conduct a cold startup, as components need to be heated gradually to avoid thermal stress and damage as a result. If the plant has not completely cooled down, it can conduct a warm startup that takes less time than a cold startup. If the plant has been briefly shut down, it can conduct a hot startup, which takes around 1 hour. In comparison to gas-fired power plants, coal-fired power plants are slower in ramping up their production.

Coal-fired power plants are often used for baseload or intermediate loads. By operating below their nominal capacity, coal-fired power plants may provide upregulating power in case another power plant suddenly shuts down. If some coal plants have been deliberately turned off, while others are running at full capacity, the up-regulation capacity is significantly reduced, as the coal-plants must conduct a cold startup in the case of a power plant outage, instead multiple coal-fired power plants ramping up.

Since coal-fired power plants are large units of several hundred MW, the failure of a power plant may bring the power system out of balance if the access to fast-regulating reserve units or flexible consumers present is insufficient.

Taking the considerations above into account, coal-fired power plants are expected to deliver a medium level of grid balancing capability.

**P11: Requirements for electricity grid infrastructure (R)**

As coal-fired power plants have a high electricity generation capacity with a high minimum load, the requirement for the electricity grid infrastructure is quite high. The coal-fired power plants need to be connected to the transmission grid through a transformer.

As the LTE or repair of coal-fired power plants are conducted on existing facilities, it can be assumed that the plants are already integrated into the power grid and placed in areas where the power is easily dispatched. So, unless the electricity grid infrastructure has been destroyed, there will be no need for further improvements to the power grid.

**P12: Requirements for skilled staff for operation and maintenance and for special spare parts (R)**

To keep a coal-fired power plant in operation, operations-, maintenance-, instrumentation-, electrical- and mechanical technicians are required. Depending on the plant size, some of these technicians might not be needed for full-time employment but can be called in when there is a specific problem regarding their field of work. Operations technicians are needed for full-time employment, so they can operate the plant from its control room. The requirement for skilled labour is considered to be low in comparison to other technologies.

**P13: Possibility for camouflage and sheltering (R)**

There is no possibility for camouflage of existing or repairable coal-fired power plants, as they are large and immovable. Moreover, their location can be assumed to be well known by Russian intelligence.

Large parts of the coal-fired power plants cannot be sheltered, but some critical components, such as the transformer, may be reinforced or covered with steel plating to minimize the damage from a direct strike on the plant. The transformer is relatively small and therefore can be sheltered; furthermore, it is a critical component that would take up to a year for a supplier to deliver as brand new.

All in all, the possibility of camouflage and sheltering is considered to be low.

**P14: Risk associated with fuel supply (R)**

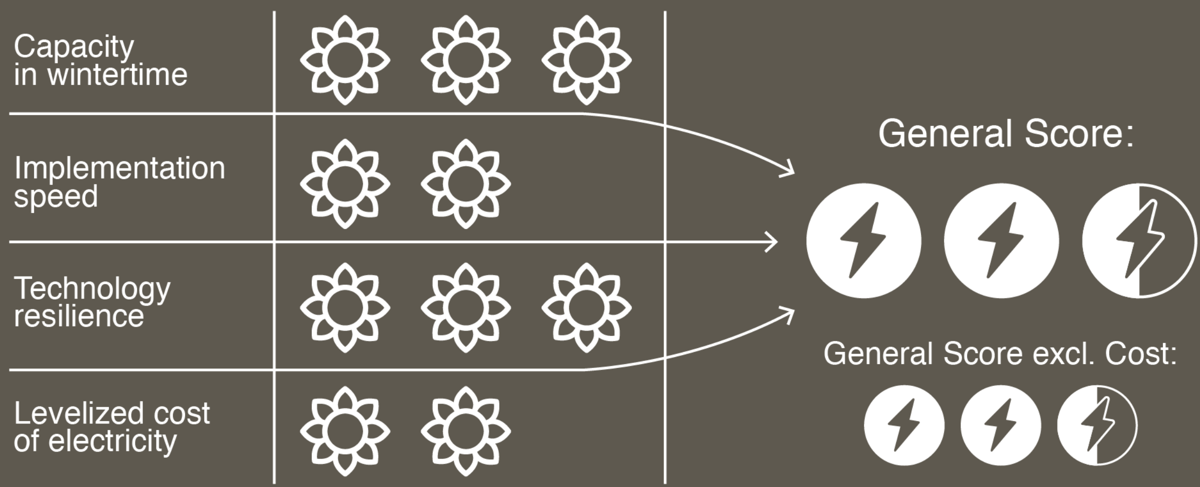
The majority of Ukrainian coal, which was used to fire the coal plants, originated from Ukrainian coal mines in the Donbass region. At the present time, this region is either occupied by Russian forces or an active warzone, which means the coal mines are inaccessible for mining. This means that coal for the power plants needs to be sourced from the international market. Which means that the availability of coal has significantly dropped for the Ukrainians, meaning that coal as a fuel is less reliable than before the war.

Although, through freight trains running through Europe, coal can be purchased on the international markets and transported to the Ukrainian powerplants. Therefore, the risk associated with coal as a fuel supply is expected to be in the **medium** range.

**P15: Restoration time (R)**

The expected restoration time of a damaged coal-fired power plant is expected to take around 65 weeks, which is the time that I would take to acquire new components, as well as implementing the repairs. In comparison to the time for some of the other technologies, the restoration time lies in between other technologies.

# BIOMASS COGENERATION TECHNOLOGIES:



## 4.7. Biomass cogeneration technologies

The rating on the front page shows the score for the technology achieving the highest general score among the sub technologies evaluated in the chapter. The more icons, the better performance[23]. For the biomass CHP, it is for all biomass types the small CHP (Organic Rankine cycle) plants that achieve the best score. The scores for all sub-technologies are shown in the table below.

*Table 31: Solid biomass CHP – overall criteria evaluation matrix*

| Criteria evaluation | 7.a. Wood pellets, CHP medium | 7.b. Wood pellets, CHP Small | 7.c. Wood Chips, CHP Medium | 7.d. Wood Chips, CHP Small | 7.e. Straw/ stalks/ husk, CHP Medium | 7.f. Straw/ stalks/ husk, CHP Small |
|---|---|---|---|---|---|---|
| Winter impact | WWW | WWW | WWW | WWW | WWW | WWW |
| Implementing speed | Q | QQ | Q | QQ | Q | QQ |
| Resilience | RR | RRR | RR | RRR | RR | RRR |
| Cost (LCOE, wintertime 2 years lifetime) | CCC | CC | CC | CC | CC | CC |
| General score (1-3) | 2.3 | 2.4 | 2.2 | 2.4 | 2.2 | 2.4 |
| General scores (excl. cost) (1-3) | 2.3 | 2.5 | 2.3 | 2.5 | 2.3 | 2.5 |

This chapter covers the possibility of constructing new biomass-fired combined heat and power plants (CHP), to supply Ukraine with electricity and heat. These types of biomass-fired CHPs are:

- CHP, back pressure, fuelled by wood pellets
- CHP, organic Rankine cycle, fuelled by wood pellets
- CHP, back pressure, fuelled by wood chips
- CHP, organic Rankine cycle, fuelled by wood chips
- CHP, back pressure, fuelled by straw/stalks/husk
- CHP, organic Rankine cycle, fuelled by straw/stalks/husk

Back pressure technologies can be manufactured across a broad spectrum of sizes, ranging from around tenths of megawatts to hundreds of megawatts. Organic Rankine cycle technologies range from a few kilowatts to multiple megawatts. In this project, the focus is on back pressure CHPs with 5-25 MWe capacity and organic Rankine cycle CHPs with 0.5-3 MWe capacity.

**Technologies relevant for the next version: Small scale fixed bed biomass gasifier CHP**

During the course of the project, we have come across a novel technology that might prove promising for the Ukrainian conditions. The German manufacturer Spanner Re² provides small scale skid based or container based thermal biomass gasifier/genset units converting dried wood fuel into 70 kWe and heat. About 1 200 units have been installed globally, and they are produced in serial production. These units have proven very

[23] See detailed explanation in Table 2: Overview of the parameters contributing to each criterion, along with the corresponding ratings. The number of icons represents the quality of the rating with more icons indicating a better rating.

durable and with some flexibility regarding fuel quality. The generator is based on a diesel tractor engine modified for syngas. The heat can be utilized to dry the fuel wood either in a system provided by the company or in simple setups.

## 4.7.1. Solid biomass for energy in UA

This paragraph describes the potential for supply of biomass for energy purposes in Ukraine.

### 4.7.1.1. Estimated potential for energy utilization of the different solid biomass types

Not all types of solid biomass are suitable for use in all energy conversion technologies. Consequently, we have evaluated the suitability of solid biomass types relevant to the Ukrainian context for use in various energy technologies.

Table 32 presents a comprehensive overview of this assessment. It reveals that among the agricultural residues evaluated, only grain straw and sunflower husks have long-standing and robust experiences as fuel sources for thermal power plants and combined heat and power (CHP) facilities. Therefore, these biomass types are deemed well-suited for this purpose. The same applies to forest residues or industrial residues such as wood chips and wood pellets.

Other agricultural residues such as rapeseed straw, stalks and cobs of maize, and stalks and heads of sunflowers are considered suitable for use in thermal power plants and CHP facilities, but there is a lack of extensive and well-documented experiences with their utilization in these applications (indicated by (+) in the table). This suggests that while these residues have potential, their use is not as established or proven as that of grain straw, sunflower husks, and forest residues.

*Table 32: Evaluation of biomass feedstock suitability for various energy conversion technologies.*

| | **Suitable for:** | | | |
|---|---|---|---|---|
| **Technologies** | **Power and CHP directly via combustion** | **Thermal gasification (synthetic gas)** | **Anaerobic digestion (biogas)** | **Pelleting for export for energy purpose** |
| **Agricultural residues** | | | | |
| Straw of grains | + | (+) | + | -* |
| Straw of rapeseed | (+) | (+) | - | - |
| Stalks and cobs of maize | (+) | - | + | - |
| Stalks and heads of sunflower | (+) | - | + | - |
| Husk of sunflower | + | (+) | - | + |
| **Forestry residues products** | | | | |
| Wood pellets | + | + | - | + |
| Wood chips | + | + | - | + |

In Table 32 “+“ indicates that the biomass can be used in the energy technology, and its use is widespread with good and robust experiences in its application. (+) indicates that the biomass can be used in the energy technology, but it is not widespread, so it is not considered immediately straightforward, and there are no robust

experiences with it. "-" indicates that the biomass is assessed to be unsuitable for use in the energy technology.
* Pellets made from straw of grains can be utilized for bedding material and potentially anaerobic digestion, but straw pellets cannot be used for combustion or gasification.

Furthermore, biomass typically requires preprocessing before utilization in energy plants. Common pretreatment methods include drying, baling, palletization, and ensiling. While crucial for efficient energy conversion, these preprocessing steps are not detailed in this section. The focus here is on the suitability of various biomass types for different energy technologies, assuming appropriate pretreatment has been applied.

**Overview of the energy potential of local solid biomass residues**

In Table 33 the theoretical potentials and the economic potentials for energy from solid biomass residues in Ukraine (in 2019) is shown. Straw of grains, stalks and cobs of maize provides the largest potential, and it is estimated that the economic potential is around 40% of the theoretical potential for most agricultural residues, except for sunflower husk. In the paper "Prospects for Bioenergy Development in Ukraine: Roadmap until 2050, Ecological Engineering & Environmental Technology 2021" it is stated that currently, agricultural residues are only utilized to a limited extent, despite the high potential, while the potential for wood biomass is almost totally exploited.

*Table 33: Solid/dry agricultural residues and forestry residues, "Theoretical potential" and "Economical potential (%)" 2019 taken from Table 1 in "Prospects for Bioenergy Development in Ukraine: Roadmap until 2050", Ecological Engineering & Environmental Technology 2021, 22(5), 73-81*

| Agricultural residues | Theoretical potential (2019) | | Economic potential, (% of theoretical potential) | Share of total Economic potential for agricultural residues | Currently (2019) utilized for energy purposes (% of economic potential) |
|---|---|---|---|---|---|
| | Mt/year | PJ/year | | | |
| Straw of grains | 37.5 | 525 | 30% | 35% | 4% |
| Straw of rapeseed | 5.9 | 89 | 40% | 7% | 4% |
| Stalks and cobs of maize | 46.6 | 513 | 40%[24] | 33% | |
| Stalks and heads of sunflower | 29.0 | 319 | 40% | 15% | |
| Husk of sunflower | 2.6 | 44 | 100% | 10% | 75% |
| Total agricultural residues | **121.6** | **1 489** | | | |
| **Forestry residues (woody biomass)** | **Theoretical potential (2019)** | | **Economic potential, (% of theoretical potential)** | **Share of total Economic potential for agricultural residues** | **Currently (2019) utilized for energy purposes (% of economic potential)** |
| | **Mt/year** | **PJ/year** | | | |
| Wood biomass such as fuel wood, logging residues, wood working waste | 7.4 | 122 | 95% | 63% | 99% |
| Wood biomass such as deadwood, wood from shelterbelt forests, biomass from agrarian plantation pruning and removal | 8.8 | 145 | 45% | 37% | 99% |
| | **16.2** | 267 | | | |

24 [Agrobioheat MAIZE RESIDUES TO ENERGY, CERTH, UABIO, 2022] The data reported in the literature on the sustainable removal rates of maize residues constitute from 25% to 70%. In this energy biomass potential assessment, the removal rate of 40% for maize residues is considered.

The potential for utilization of local solid biomass in Ukraine for electricity and combined heat and electricity production is described in the separate report “Local Ukrainian biomass – potential, collection, and treatment processes”.

## 4.7.2. Brief technology description – Back pressure

This chapter focuses on solid biomass for combustion destined to combined heat and power generation (CHP). Wood chips, wood pellets, and straw/stalks are considered for the biomass plants. Other types of biomasses, e.g., other forest industry residues; sawdust and nut shells may be relevant as energy sources, while different fuels set different technical requirements for the plant, these differences will not be addressed.

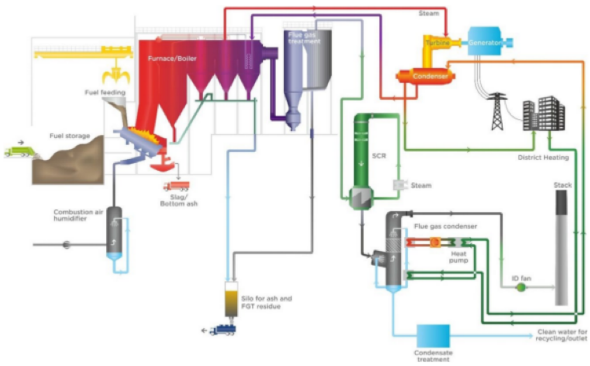



*Figure 25: Main systems of a CHP facility, example waste to energy CHP facility [Technology Data – Energy Plants for Electricity and District heating generation, 2016, Danish Energy Agency]*

The main systems are presented in Figure 25. The core components of a biomass fired backpressure CHP plant are:

- Fuel reception and storage area
- Furnace or firing system including fuel feeding
- Steam boiler
- Steam turbine and generator
- Flue gas treatment (FGT) system potentially including an SCR-system for NOx reduction
- Systems for handling of combustion and flue gas treatment residues
- Optional flue gas condensation system
- Optional combustion air humidification system

The energy contained in the biomass is extracted through the combustion of the fuel, inside a combustion chamber. The biomass is dried and decomposed into gases that are oxidized by addition of combustion air. The heat from the process is exchanged into water both in the walls of the combustion chamber and in the boiler, heating it to high temperatures, and transforming the water to steam. The steam is led through a turbine connected to a generator, to produce electricity. The steam is then condensed back to water through a heat exchanger that uses the waste heat in a district heating grid. CHP production from biomass has been used in an increasing scale for many years utilizing different technologies. The turbine is either a backpressure or an extraction turbine. In the backpressure turbine, the expansion ends in the district heat condensers; in the extraction unit, the expansion is extended to the lowest possible pressure, which is provided by a water-cooled condenser. Extraction units may run in backpressure or condensing mode as well as every combination in between. Apart from supplying heat for district heating, these plants are also relevant for industries that need steam for their process and have an electricity demand.

Application of flue gas condensation for further energy recovery is common at biomass fired boilers using feedstock with high moisture content, e.g., wood chips, except at small plants below 1-2 MWth input due to the additional costs. Plants without flue gas condensation are typically designed for biomass fuels with less than 30% moisture content. Flue gas condensation may raise the heating efficiency by 5-10% and thus, in practice, increase the heat capacity without increasing the fuel demand. However, a cold return temperature is required to exploit the qualities of a condenser.

## 4.7.3. Brief technology description – Organic Rankine Cycle

An alternative type of CHP plant is the organic Rankine cycle plants (ORC plants), where a (biomass) boiler is used for heating (no evaporation) thermal oil. This heated oil transfers heat to an ORC plant that is similar to a steam cycle but uses a refrigerant instead of water as a working medium.

To keep investments costs low, ORC plants are normally delivered in standardized complete modules in combination with 'a boiler' that only is used for heating oil. The ORC technology is a waste heat recovery technology developed for low temperature and low-pressure power generation. The ORC unit is a factory-assembled module making them less flexible but relatively cheap and thus more attractive, particularly for small-scale CHP facilities. The 'Rankine' part indicates that it is a technology with similarities to water-steam (Rankine) based systems.

The main difference being the use of a medium, i.e., a refrigerant or silicone oil (an organic compound that can burn but does not explode) with thermodynamic properties that make it more adequate than water for low temperature power generation[25].

## 4.7.4. Criteria evaluation – Biomass CHP medium scale back pressure

*Table 34: Criteria evaluation matrix for back pressure CHPs using wood pellets, -chips and straw as fuels*

| Criteria evaluation | 7.a. Wood pellets, CHP medium | 7.c. Wood Chips, CHP Medium | 7.e. Straw/stalks/husk, CHP Medium |
|---|---|---|---|
| Winter impact | WWW | WWW | WWW |
| Implementing speed | Q | Q | Q |
| Resilience | RR | RR | RR |
| Cost (LCOE, wintertime 2 years lifetime) | CCC | CC | CC |
| General score (1-3) | 2.3 | 2.2 | 2.2 |
| General scores (excl. cost) (1-3) | 2.3 | 2.3 | 2.3 |

**Winter impact, production at wintertime (W)**

Biomass back pressure Combined Heat and Power (CHP) plants have the potential to significantly contribute to the Ukrainian power system, particularly during winter. In addition to supplying power, these plants can provide heating to local urban areas. They have the ability to regulate their generation, enabling them to operate at full

25 Example of utilization of ORC

capacity in the colder months. However, it is important to note that unlike gas turbines or engines, biomass back pressure CHP plants are unable to just as rapidly scale their production.

**Implementing speed (Q)**

All in all, the Implementing time for the medium size CHP (back pressure) are assessed to be long. The timeline for the implementation of a biomass back pressure CHP plant hinges significantly on the project size. The planning process for such a plant is expected to be around half a year. The time for delivery of components, after a biomass back pressure CHP plant has been ordered, is expected to be almost one and a half years, while based on previous experience, installation time is estimated to take around one year. But given that it is typically possible to start the construction work before all components are delivered, the total time from when the final decision is made until the plant can be put into operation is only between 2 and 2.5 years, accounting for planning and regulatory approvals, the overall project delivery time, and the installation time.

During the interviews it is highlighted that there may be opportunities to significantly accelerate the process for the projects. For example, if authorities are positive towards a project but still need time to process the approval, it may be possible to enter into an agreement with the client for an engineering contract and, based on that, place orders with subcontractors for key components with long lead times such as the turbine and boiler. There are examples of this in Europe, but whether it is possible in Ukraine cannot be determined.

**Resilience (R)**

The resilience of medium size biomass CHP (backpressure) plants is assessed to be medium. The resilience of biomass CHP (back pressure) hinges on serval key factors. First, these plants, each with a capacity of around 5-25 MW, can be strategically distributed across a wide geographic area. Despite the relatively large footprint of a 25 MW biomass back pressure CHP plant, its design permits a significant portion of the power plant to be bunkered and the same applies to the fuel, enhancing its resilience. However, this does not apply to the chimney. The risk of fuel supply disruption is assessed to be low, as it is assumed that there are multiple supply options. Their ability to support grid stability is considered **medium**, as they have a certain inertia in ramping up and down. The reconstruction time is set to **medium**.

For the smaller units even more so, they can be built in anonymous-looking buildings resembling a workshop, a farm, or a barn.

**Generation costs (LCOE), short term and over the lifetime (C)**

Considering the Levelized Cost of Energy (LCOE), both short-term and over the lifetime, biomass back pressure CHP plants exhibit a competitive edge. When operational over two winters, these plants demonstrate a lower LCOE compared to several other evaluated technologies. The LCOE falls in the medium range. Over their lifetime, the LCOE for these plants, when using wood pellets and chips as fuel, is also categorized as medium. For all biomass CHP technologies, the costs of electricity generation are dependent on the revenues from selling heat to district heating companies.

## 4.7.5. Parameter evaluation – Back pressure CHP plants

This section covers the parameter evaluation of biomass CHP medium scale back pressure that was used as the basis for the criteria evaluation.

*Table 35: Parameter evaluation matrix of biomass CHP medium scale back pressure plants. The LCOE unit is [€//MWh]*

| Criteria evaluation | 7.a. Wood pellets, CHP Medium | 7.c. Wood Chips, CHP Medium | 7.e. Straw, CHP Medium |
|---|---|---|---|
| P1-Electricity production at wintertime | >75% | >75% | >75% |
| P2-Levelized Cost of Electricity (LCOE) short lifetime, winter production [€/MWh] | 1 087 | 1 256 | 1 250 |
| P3-Levelized Cost of Electricity (LCOE) over lifetime [€/MWh] | 141 | 142 | 126 |
| P4-Distributed generation | Medium | Medium | Medium |
| P5-Regulation requirement in the project development process | In between | In between | In between |
| P6-Delivery time and availability of components and materials | In between | In between | In between |
| P7-Requirements for logistics and transportation infrastructure | Low | Low | Low |
| P8-Technical installation time (after clearance) | Lengthy and complicated | Lengthy and complicated | Lengthy and complicated |
| P9-Requirements for skilled staff in construction phase | Medium | Medium | Medium |
| P10-Grid balancing capacity | Medium | Medium | Medium |
| P11-Requirements for electricity grid infrastructure | Easy | Easy | Easy |
| P12-Requirements for skilled staff for operation and maintenance and for special spare parts | Low | Low | Low |
| P13-Possibility for camouflage and sheltering | Medium | Medium | Medium |
| P14-Risk associated with fuel supply | Low risk | Low risk | Low risk |
| P15-Restoration time | In between | In between | In between |

**P1: Electricity production in wintertime (W)**

If there is fuel available and a sufficient demand for district heating, biomass back pressure CHP plants may operate at their full capacity any hour of the day, except for the planned and forced outages. Depending on the specific CHP plants, there are different requirements for when the plant should be refurbished, meaning that there will be some weeks of the year where it is planned that the biomass plants will be out of operation. Typically, the refurbishment is planned to be done during the summer, when the need for the plant is lower. Forced outages can happen for multiple reasons but typically occur due to some form of breakdown taking place during production.

As mentioned, the need for biomass CHPs is lower during the summer. The power consumption is normally lower. Furthermore, there is competition against VREs and other power plants.

During summer, electricity generation from biomass back pressure plants may be constrained by a low demand for heat unless situated at an industry with a more constant process heat demand. Extraction plants provide a higher degree of flexibility as they can run in condensing mode when the heat demand is insufficient.

Due to these reasons, it is assumed that a biomass CHP plant will operate, to what equates as, full capacity for 5 000 hours during a year, so-called Full Load Hours (FLH). As the majority of the production is likely to happen during the winter period, it is assumed that 75% of the FLH will occur during the wintertime, which means that it is assumed that a biomass CHP will operate with 3 750 full load hours during wintertime (86% capacity factor). This corresponds to the annual FLH of a wind turbine located in the Ukrainian region with the best wind profiles and above twice the annual FLH of a PV plant located in the Ukrainian region with the best solar profile. Furthermore, biomass back pressure CHP plants are expected to generate power in intermediate and base load hours, which means that the FLH for biomass back pressure CHP plants can be expected to be higher than gas engines and turbines.

**P2: Levelized Cost of Electricity (LCOE) short lifetime, winter production (C)**

In the emergency scenario, where the biomass back pressure CHP plants are only utilized for two winter periods, the LCOE is close to the low end of the medium range. The LCOE is calculated to be €1 087/MWh for a wood pellet plant, €1 256/MWh for a wood chip plant and €1 250/MWh for a straw-fired plant.

Most of these costs are tied to the CAPEX and finance costs, as the plants will not be able to deliver power for their full lifetime expectancy. Please note that the fuel prices used in these calculations are Danish fuel prices, however, the straw price is reduced by 25%.

**P3: Levelized Cost of Electricity (LCOE) over lifetime (C)**

The LCOE over the wood pellet back pressure CHP plants lifetime is expected to be approximately €141/MWh. The LCOE for the wood chip back pressure CHP is calculated to be €142/MWh and for the straw-fired back pressure CHP LCOE over the lifetime is calculated to be €126/MWh. These LCOE results belong in the **medium** price range. These costs are around 3-4 times higher than onshore wind power and utility-scale photovoltaics but equivalent to new gas engines and turbines.

The generation costs of biomass back pressure CHP plants are approximately equally distributed among operational expenses (OPEX), fuel costs, and capital expenditures (CAPEX). Please note that the fuel prices used in these calculations are Danish fuel prices, however, the straw price is reduced by 25%.

**P4: Distributed generation (R)**

Biomass back pressure Combined Heat and Power (CHP) plants are projected to have a power generation capacity of 5-25 MWe. This capacity is in between when compared to wind turbines and gas engines but decentralized in comparison to coal-fired power plants or nuclear power plants.

Physically, there are options to limit the footstep of a biomass CHP plant. Plants with capacities in the low range of the span can quite easily be fitted into small and anonymously looking buildings.

While the size of the boiler sections and the steam turbine units of these plants will be similar across fuels, the fuel storage and handling systems vary, pellets being the smallest, wood chips requiring storage and auger systems, and straw requiring a barn and also a “straw table” in front of the shredding and feeding mechanism containing a number of bales to fit one day of operation. However, at small plants with semi manual fuel handling, it would be easy to separate the plant and the fuel storage.

For wood chips, the fuel – if dry – needs cover but it could be simple, otherwise it can simply be stored in piles directly after chipping. Then the fuel could be transported locally to one or more plants by a tractor with trailer and fed into a hopper containing the short-term fuel demand, and the same counts for straw. Bales can be stored in a field in small or larger quantities covered in plastic or potentially uncovered (in case it is OK to lose the outermost bales), and then transport the bales locally by a front loader with forks and trailer to fill up the “straw table” with bales to cover the short-term demand. As a result, the capability of biomass back pressure CHP plants to provide distributed power generation is considered to be rather high.

In light of the current situation in Ukraine, there are several arguments in favour of distributed installations. These installations, strategically located near demand centres, have the advantage of reducing reliance on the transmission grid. This mitigates the risks associated with potential losses in power production capacity. Furthermore, generating power locally at the end-user's site reduces the need for extensive electricity transmission, thereby enhancing energy security. Also, these plants typically are equipped with synchronous generators that allow them to operate autonomously, should the transmission grid fail. They do not need the grid to magnetize the generator as is needed with asynchronous generators.

**P5: Regulation requirement in the project development process (Q)**

With a capacity of 5-25 MW, biomass CHP (back pressure) plants are not anticipated to significantly impact the local environment. This suggests that the environmental approval process could be more straightforward compared to larger facilities. Their relatively modest capacity also implies that the grid connection approval process will be less complex than for larger power plants.

Despite these benefits, biomass CHP (back pressure) plants do have a footprint, necessitating time for the acquisition of suitable property. Taking these factors into account, the planning and regulatory process for a biomass back pressure CHP plant is estimated to span approximately 26 weeks. This duration places the planning process and regulatory approval within the **medium** range. The time might be shorter for plants at the low end of the range.

**P6: Delivery time / availability of components and materials (Q)**

The total time frame for 5-10 MWe plants from ordering the plant until it is operational (i.e. delivery and installation) is 18-24 months, according to interviewees. This counts for normal/easy fuels like clean wood and straw. Fuels with different composition, e.g., containing corrosive substances (waste wood), normally require more advanced steel coatings in the boiler, which requires more time. Installation works normally start after 6 months and continue until the plant is ready for testing. Deliveries go on in parallel throughout the process. The suppliers mention that turbine delivery typically is the most limiting factor that can normally not be influenced, as the manufacturers are large companies that fit in with new orders one by one. Boiler manufacturing also takes time, but most manufacturers keep stock of steel or have close connections to steel works.

Despite the process described above, for practical reasons the delivery time is set to be 52 weeks. Straw fired and moist wood chips fuelled units typically require more advanced equipment in the fuel storage and fuel handling here. We have added 5 additional weeks due to the complexities involved in handling different fuel types and introducing them into the plant's combustion chamber. For instance, conveying wood pellets into the combustion chamber is simpler compared to straw. Straw requires transportation via a conveyor belt or crane lift to be deposited into the combustion chamber through a hatch, while wood pellets can be injected via a screw pump.

Some suppliers suggest the option for early ordering, meaning that once authorities are positive about a project but still need time for processing the approval; it is possible for the supplier to agree with the client on an engineering contract and, based on the engineering work, place orders at sub-suppliers for key components such as the turbine and the boiler. This option is considered here.

Ukraine has a boiler manufacturing industry, producing one of the most advanced boilers for biomass burning up to 10 MWth in capacity. Additionally, larger boilers, ranging from 200-300 MW, are also produced in Ukraine, catering to both biomass and coal energy production.

**P7: Requirements for logistics and transportation infrastructure (Q)**

The suppliers underline that all units and construction components are designed for unrestricted road transport on normal 25 t trucks. All that is needed is access to a normal road that also counts for fuel deliveries once the plant is operational. Consequently, the requirements for logistics and transportation infrastructure are categorized **easy**.

**P8: Technical installation time (min time after clearance) (Q)**

Please refer to P6. The anticipated installation time for the wood pellet back pressure CHP plants is 52 weeks, while in practice installations take place in parallel to deliveries of further equipment.

**P9: Requirements for skilled staff in construction phase (Q)**

During the construction phase of a biomass back pressure CHP plant, a diverse workforce is required, including general labourers, heavy equipment operators, concrete workers, welders, plumbers, electricians, HVAC technicians, and safety specialists. These workers can either be sourced locally in Ukraine or brought in from other countries, subject to company policies. If security concerns prevent companies from sending their employees to Ukraine, it is plausible that they might opt to train local labourers.

Each medium-sized biomass back pressure CHP plant is unique and not based on modular builds, necessitating the presence of engineers during certain stages of construction to ensure quality control. Engineers are also required to modify building schematics if any aspect of the construction does not proceed as planned. This is a common issue for tailor-made plants, unlike modular build solutions that are well-tested. Consequently, the need for skilled staff during the construction phase is considered to be of medium level.

According to information provided by the Ukrainian partners, Ukraine is facing a significant labour shortage, estimated to be up to 5 million workers, across all sectors due to the impacts of war and migration. This shortage is particularly noticeable in specialized fields such as biogas and biomethane installations, where there is a lack of qualified professionals. Therefore, it might be hard to source the number of labourers needed for a large construction project.

**P10: Grid balancing capacity (R)**

Provided that biomass is readily available and the demand for heat is sufficient, a biomass back pressure CHP plant can generate electricity at any time of day. A cold startup, which involves gradually heating components to prevent thermal stress and damage, can take several hours. If the plant has not fully cooled down, it can undergo a warm startup, which is quicker and typically takes around 15 minutes. Compared to gas-fired power plants, biomass back pressure CHP plants take longer to ramp up their production.

Biomass back pressure CHP plants may influence the grid balance if they are disrupted causing their production to cease abruptly. Given these factors, biomass back pressure CHP plants are expected to offer a **medium** level of grid balancing capability.

Taking the considerations above into account, Biomass back pressure CHP plants are expected to deliver a medium level of grid balancing capability.

**P11: Requirements for electricity grid infrastructure (R)**

As biomass back pressure CHP plants have a moderate electricity generation capacity, the requirement for the electricity grid infrastructure is low, as these plants can be connected to the medium voltage grid. Suppliers stress that the plants can often operate autonomously supplying electricity for local consumption.

**P12: Requirements for skilled staff for operation and maintenance and for special spare parts (R)**

Maintaining the operation of a biomass back pressure CHP plant requires a team of technicians specializing in operations, maintenance, instrumentation, electrical, and mechanical work. The need for full-time employment of these technicians can vary depending on the size of the plant and with the fuel type and fuel delivery choices, with some only required to address specific issues related to their field of expertise. However, operations technicians are essential for full-time roles, as they manage the plant from its control room. Compared to other technologies, the demand for skilled labour in this context is considered to be low.

**P13: Possibility for camouflage and sheltering (R)**

Camouflaging a biomass back pressure CHP plant at the high end of the size range is not feasible due to their size and visibility via satellite imagery. But the plant can easily be anonymized with appropriate cladding making the plant blend into the surroundings.

While the majority of the plant cannot easily be sheltered, certain critical components, such as the turbine and generator as well as the transformer, can be reinforced or shielded with steel plating to mitigate damage from direct strikes. Given its relatively small size, the transformer can be effectively sheltered. Furthermore, it is worth noting that this component is critical, and it could take up to a year or more to replace it if procured new from a supplier.

Plants at the lower end of the range do not take up much space and can be fitted into potentially existing buildings or simple steel barns and might look like a farm or small factory. Fuel may be stored a bit away to not attract attention – please refer to P4. Overall, the prospects for camouflage and sheltering are considered to be **medium** range.

**P14: Risk associated with fuel supply (R)**

The majority of the biomass for the back pressure CHP plants is anticipated to originate from Ukraine, which has a strong agricultural sector capable of producing substantial amounts of straw post-harvest. Additionally, the wood required for pellets and chips can be procured from Ukraine's own forests, either through selective harvesting or through utilization of waste wood.

**P15: Restoration time**

The restoration time for biomass back pressure CHP plants is classified as **medium**. Depending on the extent of the damage, the plants can be repaired efficiently with the right equipment and skilled technicians. Spare parts are typically delivered relatively quickly.

## 4.7.6. Criteria evaluation – Biomass CHP organic Rankine cycle

*Table 36: Criteria evaluation matrix for organic Rankine cycle plants, using wood pellets, wood chips and straw as fuel*

| Criteria evaluation | 7.b. Wood pellets, CHP Small | 7.d. Wood Chips, CHP Small | 7.f. Straw/stalks/husk, CHP Small |
|---|---|---|---|
| Winter impact | WWW | WWW | WWW |
| Implementing speed | QQ | QQ | QQ |
| Resilience | RRR | RRR | RRR |
| Cost (LCOE, wintertime 2 years lifetime) | CC | CC | CC |
| General score (1-3) | 2.4 | 2.4 | 2.4 |
| General scores (excl. cost) (1-3) | 2.5 | 2.5 | 2.5 |

**Winter impact, production at wintertime (W)**

Small ORC-based biomass CHP plants can contribute to the Ukrainian power system during wintertime. Furthermore, they can deliver heating to the local urban areas. Small biomass CHP (ORC) plants can regulate their generation, allowing them to produce at full capacity during wintertime. Although, the ORC CHP plants cannot scale their production as quickly as gas turbines or engines.

**Implementing speed (Q)**

The timeline for the implementation of a small biomass-fired CHP (ORC) plants hinges significantly on the project size and specifically on the delivery of the ORC unit(s). The planning process for such a plant is expected to be around 20 weeks, and the total time for delivery and installation after the equipment for the biomass-fired ORC CHP plant has been ordered is expected to be around 40 weeks. In practice, this is defined by the delivery time of the ORC plant, added 2 weeks for installation. This leaves time to manufacture and install the boiler system, even when straw based. Thus, the total time from the final decision is made until the plant can be put into operation is between one and one and a half years. Accounting for planning and regulatory approvals, the overall project delivery time, and the installation time. This time frame is considered to lie within the **medium quick** category.

**Resilience (R)**

The resilience of the small biomass CHP (ORC) plants is assessed to be **good**. The resilience of biomass ORC CHP plants is linked to several factors. Firstly, plants with a capacity of 0.5-3 MWe can be spread over a large geographical area, thereby delivering a combined significant production capacity. Secondly, the footprint of a 0.5-3 MWe biomass CHP (ORC) plant is relatively high in relation to its production capacity, but at the same time, a large part of the power plant can be protected with a concrete roof, and the same applies to the fuel. However, this does not apply to the chimney. The risk of fuel supply disruption is assessed to be low, as it is assumed that there are multiple supply options. Their ability to support grid stability is considered medium, as they have a certain inertia in ramping up and down. The reconstruction time is set to medium.

**Generation costs (LCOE), short term and over the lifetime (C)**

The Levelized Cost of Energy (LCOE) for biomass ORC CHP plants is considered **medium** when production is limited to only two winter seasons. However, over the plant's lifetime, the LCOE becomes high due to the relatively low electrical efficiency of the technology. This inefficiency leads to higher fuel consumption per unit of electricity produced, significantly increasing fuel costs compared to biomass back-pressure CHP plants. Recent interviews indicate that ORC solutions may be more viable than previously assumed, though challenges remain. However, the overall efficiency of these systems is low, around 10%, underscoring the importance of deriving value from the heat produced alongside electricity.

## 4.7.7. Parameter evaluation – Organic Rankine cycle plants

This section covers the parameter evaluation of biomass-fired ORC CHP plants, which is used as the basis for the criteria evaluation.

*Table 37: Parameter evaluation matrix of biomass-fired ORC CHP plants. The LCOE unit is [€//MWh]*

| Criteria evaluation | 7.b. Wood pellets, CHP Small | 7.d. Wood Chips, CHP Small | 7.f. Straw, CHP Small |
|---|---|---|---|
| P1-Electricity production at wintertime | >75% | >75% | >75% |
| P2-Levelized Cost of Electricity (LCOE) short lifetime, winter production [€/MWh] | 1 273 | 1 304 | 1 368 |
| P3-Levelized Cost of Electricity (LCOE) over lifetime [€/MWh] | 186 | 175 | 168 |
| P4-Distributed generation | Good | Good | Good |
| P5-Regulation requirement in the project development process | In between | In between | In between |
| P6-Delivery time and availability of components and materials | In between | In between | In between |
| P7-Requirements for logistics and transportation infrastructure | Low | Low | Low |
| P8-Technical installation time (after clearance) | Medium-term | Medium-term | Medium-term |
| P9-Requirements for skilled staff in construction phase | Medium | Medium | Medium |
| P10-Grid balancing capacity | Medium | Medium | Medium |
| P11-Requirements for electricity grid infrastructure | Easy | Easy | Easy |
| P12-Requirements for skilled staff for operation and maintenance and for special spare parts | Low | Low | Low |
| P13-Possibility for camouflage and sheltering | Medium | Medium | Medium |
| P14-Risk associated with fuel supply | Low risk | Low risk | Low risk |
| P15-Restoration time | In between | In between | In between |

**P1: Electricity production in wintertime (W)**

If there is fuel and a heat demand available, small biomass CHP (ORC) plants may operate at full capacity any hour of the day, except for the planned and forced outages. Depending on the specific CHP plants, there are different requirements for when the plant should be refurbished, meaning that there will be some weeks of the year where it is planned that the biomass plants will be out of operation. Typically, the refurbishment is planned to be done during the summer, when the need for the plant is lower. Forced outages can happen for multiple reasons but typically occur due to some form of breakdown, which occurs during production.

As mentioned, the need for biomass CHPs is much lower during the summer, as a large share of the electricity can be generated through baseload technologies like nuclear, wind, and increasingly photovoltaics. Meanwhile, the power consumption is also lower, as amongst other reasons, the heat demand is greatly reduced. Furthermore, biomass CHP plants also compete amongst each other and against other fuel-based power plants and combined heat and power plants, which means that some of the production will be cannibalized.

Due to these reasons, it is assumed that a biomass ORC CHP plant will operate, to what equates as, full capacity for 5 000 hours during a year, so-called Full Load Hours (FLH). As the majority of the production is likely to happen during the winter period, it is assumed that 75% of the FLH will occur during the wintertime, which means that it is assumed that a small biomass CHP (ORC) plant will operate with 3 750 full load hours during wintertime (86% capacity factor). This corresponds to the annual FLH of a wind turbine located in the Ukrainian region with the best wind profiles and above twice the annual FLH of a PV plant located in the Ukrainian region with the best solar profile. If Ukrainian power plants do not cannibalize each other due to missing capacity caused by Russian bombardments, then the FLH can be expected to be higher. Furthermore, small biomass CHP (ORC) plants are expected to generate power in the intermediate and base load hours, which means that the FLH for small biomass CHP (ORC) plants can be expected to be higher than gas engines and turbines.

**P2: Levelized Cost of Electricity (LCOE) short lifetime, winter production (C)**

In the emergency scenario, where the small biomass CHP (ORC) plants are only utilized for two winter periods, the LCOE is at a medium level. The LCOE is calculated to be €1 273/MWh for a wood pellet plant, €1 304/MWh for a wood chip plant and €1 368/MWh for a straw-fired plant.

The majority of these costs are tied to the CAPEX and finance costs, as the plants will not be able to deliver power for their full lifetime expectancy. Please note that the fuel prices used in these calculations are Danish fuel prices, however, the straw price is slightly reduced. Interviewees suggest that ordering many units at a time might significantly reduce the unit price.

**P3: Levelized Cost of Electricity (LCOE) over lifetime (C)**

The LCOE over the wood pellet ORC CHP plants lifetime is expected to be approximately €186/MWh. The LCOE for the wood chip ORC CHP plants is calculated to be €175/MWh and for the straw/husk/stalks-fired ORC CHP plants it is calculated to be €168/MWh. For the wood pellet and wood chip CHP plant, this LCOE is considered to lie in the high price range. These prices are around 3 to 4 times higher than onshore wind power and utility scale photovoltaics, however almost equal the price of new gas engines and turbines.

The cost allocation of the biomass ORC CHP plants is fairly spread out between OPEX, fuel costs, CAPEX, and the finance costs. But the fuel cost, due to the limited electrical efficiency of ORC CHP technology, adds a significant markup on the price for these plants. Please note that the fuel prices used in these calculations are Danish fuel prices, however, the straw price is slightly reduced. Interviewees suggest that ordering many units at a time might significantly reduce the unit price.

**P4: Distributed generation (R)**

The power generation capacity of the biomass ORC CHP plants is expected to be 0.5-3 MWe, which means that the biomass ORC CHP plants offer an excellent choice of decentralized energy production. Physically, there are options to limit the footstep of an ORC CHP plant. Plants with capacities in the low range of the span can easily be fitted into small and seemingly unimportant buildings or barns.

While the size of the boiler sections and the ORC units of these plants will be similar across fuels, the fuel storage and handling systems vary, pellets being the smallest, wood chips requiring a storage and auger systems, and straw requiring a barn and also a "straw table" in front of the shredding and feeding mechanism containing a number of bales to fit one day of operation. However, at small plants with semi manual fuel handling, it would be easy to separate the plant and the fuel storage.

For wood chips, the fuel – if dry – needs cover but it could be very simple, otherwise it can simply be stored in piles directly after chipping. Then the fuel could be transported locally to one or more plants by a tractor with trailer and fed into a hopper containing one or a few days fuel demand, and the same counts for straw. Bales can be stored in a field in small or larger quantities covered in plastic or potentially uncovered (in case it is OK to lose the outermost bales), and then transport the bales locally by a front loader with forks and trailer to fill up the "straw table" with bales to cover the demand for one or a few days.

Based on the above, the capability of biomass ORC CHP plants to provide distributed generation is evaluated to be high.

Given the current situation in Ukraine, there are several compelling reasons to favour distributed installations. These installations, located near demand centres, offer the advantage of reducing dependence on the transmission grid, thereby mitigating the risks associated with potential power production capacity loss. Moreover, local power generation at the end-user's site diminishes the necessity for extensive electricity transmission, consequently bolstering energy security.

**P5: Regulation requirement in the project development process (Q)**

As the plants are 0.5-3 MWe capacity, they are not expected to have a large impact on the local environment, thus it can be assumed that the environmental approval process is easier. Furthermore, due to their low capacity, it can be expected that the approval process for grid connection is also easier than larger power plants. Lastly, biomass ORC CHP plants come in modular builds, which are well known and can be pre certified for operation.

Due to these considerations the planning and regulation process for a biomass ORC CHP plant is expected to take around 20 weeks. This time consumption for the planning process and regulatory approval is in the medium range.

**P6: Delivery time / availability of components and materials (Q)**

Interviews with suppliers of boiler plants and ORC units around small straw-based ORC plants (5 MWth and 500 kWe) indicate very short total delivery and installation times. While the boiler plants can be really quick (around 24 weeks in total after approval), the ORC might have a delivery time of around 36 weeks while installation time then is only 1-2 weeks given the site has been prepared. These units need to be placed on a floor, having four tubes and one cable connected and will then be ready to generate power.

Based on this, we have chosen the delivery time to be 26 weeks with installation being 12 weeks.

Delivery and installation time might increase for somewhat larger boiler/ORC units but not close to proportional.

**P7: Requirements for logistics and transportation infrastructure (Q)**

These units and the components needed for the construction are designed for unrestricted road transport on normal 25 t trucks. All that is needed is access to a normal road that also counts for fuel deliveries once the plant is operational. Consequently, the requirements for logistics and transportation infrastructure are categorized **easy**.

**P8: Technical installation time (min time after clearance) (Q)**

Please refer to P6. The anticipated installation time for the ORC CHP plant is 12 weeks, while in practice installations take place in parallel to deliveries of equipment.

**P9: Requirements for skilled staff in construction phase (Q)**

During the construction phase, general labourers, heavy equipment operators, concrete workers, welders, plumbers, electricians, HVAC technicians, and safety specialist workers are required. These labourer types should be available in Ukraine or can be sent from other countries, depending on company policies. If companies cannot send their employees to Ukraine to perform the construction due to security concerns, it is reasonable to assume that some companies can and will educate general labourers from Ukraine.

As each biomass-fired ORC CHP plant has an element to it, which might be different from another ORC CHP plant, engineers are needed in some parts of the construction phase to oversee quality control. Furthermore, engineers are needed to adjust building schematics if something in the construction does not work as expected or properly. These are common issues for plants that are tailor made, in comparison to modular build solutions that are well tested. This is why the requirement for skilled staff is considered **medium** during the construction phase.

According to estimates provided by the Ukrainian partners, Ukraine is short of up to 5 million workers. Which means that during the construction phase, it might be hard to source the number of labourers needed for a large construction project.

**P10: Grid balancing capacity (/demands) (R)**

Assuming biomass is available, a biomass ORC plant can produce electricity at any hour of the day. It takes several hours to conduct a cold startup, as components need to be heated gradually to avoid thermal stress and damage as a result. If the plant has not completely cooled down, it can conduct a warm startup which takes less time than a cold startup, approximately 15 minutes. In comparison to gas-fired power plants, biomass ORC CHP plants are slower in ramping up their production.

Biomass ORC CHP plants have a production capacity that is too low to have any noticeable effect on the grid balance if they are bombarded and their production suddenly stops.

Taking the considerations above into account, Biomass ORC CHP plants are expected to deliver a **medium** level of grid balancing capability.

**P11: Requirements for electricity grid infrastructure (R)**

As ORC CHP plants have a low electricity generation capacity, the requirement for the electricity grid infrastructure is therefore low, as these plants can be connected to the medium voltage grid with a relatively small transformer.

**P12: Requirements for skilled staff for operation and maintenance and for special spare parts (R)**

To keep an ORC CHP plant in operation, operations-, maintenance-, instrumentation-, electrical- and mechanical technicians are required. Depending on the plant size, some of these technicians might not be needed for full-time employment but can be called in when there is a specific problem regarding their field of work. Operations technicians are needed for full-time employment, so they can operate the plant from its control room. The requirement for skilled labour is considered to be in the low range, in comparison to other technologies, because the plant does have a size of 0.5-3 MWe. There may be some complicated work when maintaining the ORC unit.

**P13: Possibility for camouflage and sheltering (R)**

There is some possibility for camouflage ORC CHP plants. Depending on the need for fuel storage close by, they can be large compared to generation capacity, which might make them easier to spot, but their construction can be done so that they fit into the surroundings and the roofing can be covered with grass, which might make it harder to spot the plant via arial footage. The smokestack cannot be hidden, but the outlet can be placed further away from the rest of the plant.

Furthermore, the fuel can be delivered daily in small quantities from storages placed a bit apart from the generation units – please refer to P4. Some parts of the biomass-fired ORC CHP plant cannot be sheltered, such as the smokestack. Some critical components, such as the transformer and generator, may be sheltered to minimize the damage from a direct strike on the plant.

All in all, the possibility of camouflage and sheltering is considered to be high.

**P14: Risk associated with fuel supply (R)**

The majority of the biomass for the ORC CHP plants, is expected be of Ukrainian origin. Ukraine has extensive agriculture, which can deliver large amounts of straw, after each harvest. Furthermore, the wood for wood pellets and chips can be sourced from Ukraine's wood processing industries or stands, gardens, parks, or forests, either through selective forest harvesting or through use of waste wood.

**P15: Restoration time**

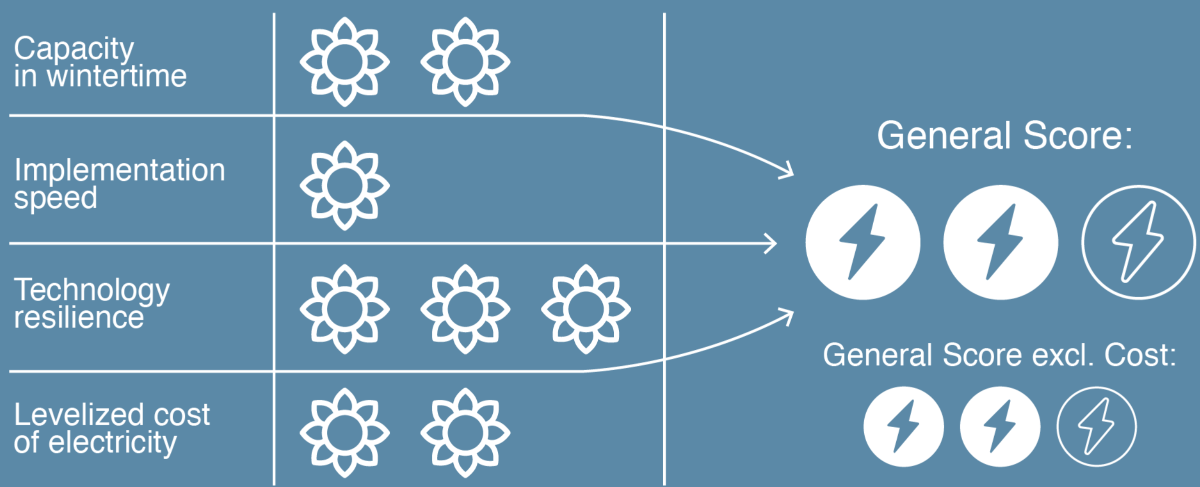
The restoration time for small biomass CHP (ORC) plants is classified as **medium**. Depending on the extent of the damage, the plants can be repaired efficiently with the right equipment and skilled technicians. Spare parts are typically delivered relatively quickly.

### 4.7.7.1. Data sheet

In Appendix F are data sheets for:

- biomass CHP backpressure, medium scale for
  - wood chips
  - wood pellets
  - straw/stalks/husk
- biomass CHP organic Rankine cycle, small scale for
  - wood chips
  - wood pellets
  - straw/stalks/husk

# HYDRO POWER


Capacity in wintertime
Implementation speed
Technology resilience
Levelized cost of electricity
General Score:
General Score excl. Cost:

## 4.8. Hydropower

The rating on the front page shows the scores for the micro/mini run-of-river (RoR) hydro power plants (HPPs), which achieved the highest general score among the HPPs sub technologies evaluated in this hydro power chapter. The more icons, the better performance[26]. It should be noticed that LCOE calculation are not available for the “Retrofit of HPPs with dams incl. PHS”, thus the technology did not achieve a “general score.” The evaluations of all criteria and sub-technologies are shown in Table 38. It shows that the retrofitting / repair of the large HPP achieves the highest score of the HPPs evaluated in this report for the general score excl. LCOE (2 years, winter). Furthermore, it is shown that RoR HPPs achieve a **medium** score for the winter impact. The same is true for winter impact of the large HPPs with dams. RoR HPPs achieve a low score for the implementing speed, while retrofitting or repairing HPPs score **medium** for this parameter. Contrary small and mini/micro RoR achieves the best score for resilience, while Large HPPs with dams score **poor** on this criterion. Small and mini/ micro RoR HPPs achieve a low score for LCOE (2 years, winter). Whereas, for the parameter LCOE (over the lifetime) small and mini/micro RoR HPPs perform better than most of the technologies in this report.

*Table 38: Hydropower – overall criteria matrix for hydropower technologies*

| Criteria evaluation | 8.a. Hydro, RoR, small | 8.b. Hydro, RoR, micro | 8.c. Retrf Hydro power, dams incl. PHS |
|---|---|---|---|
| Winter impact | WW | WW | WW |
| Implementing speed | Q | Q | QQ |
| Resilience | RRR | RRR | R |
| Cost (LCOE, wintertime 2 years lifetime) | CC | CC | n.a |
| General score (1-3) | 1.6 | 1.8 | n.a |
| General scores (excl. cost) (1-3) | 1.8 | 1.8 | 2.0 |

This section covers the small-scale hydro generator types with the capability of being more distributed to supply Ukraine with electricity. Largescale hydropower generation facilities are in principle not within the scope of this report. But the retrofit of damaged or outdated large hydropower plants are included to point out the potential.

Hydropower plants can be classified in different ways, which for instance distinguish among head availability, plant size and operational regime. In terms of operational regime, the following classification is widely accepted:

1. Run-of-river (RoR) hydro power plants
2. Storage/reservoir hydro power plants, with or without pumped storage

The types of hydro generators concerned in this section are the following international classification:

- Mini and micro run-of-river (RoR) hydro power generators ranging from few kW to 1 MW
- Small run-of-river (RoR) hydro power generators ranging from 1 MW to 30 MW
- Retrofit of existing large storage/reservoir HPPs with dams and pump storage

[26] See detailed explanation in Table 2: Overview of the parameters contributing to each criterion, along with the corresponding ratings. The number of icons represents the quality of the rating, with more icons indicating a better rating.

In the 1960s, about 1 000 small HPPs with a total capacity of about 300 MW were operating in Ukraine, the local HPPs were contributing to the rural electrification of Ukraine. In 2022, 177 small HPPs with a capacity of 120 MW were operated in Ukraine.

Before the war, the total installed hydropower capacity in Ukraine was around 6 200 MW, one fourth of the capacity includes pumped storage. About 60% of the installed hydropower capacity was built in the 1960s, and modernization and rehabilitation was deemed necessary. Therefore, before 2022 a large-scale rehabilitation program was going on to improve generation capacity, reliability, and safety of most of the existing hydropower plants. At that time, it was estimated that rehabilitation and modernization could add more than 4 000 MW of hydropower capacity in Ukraine. During the war, the rehabilitation has been stopped and many of the large HPP have been partly or totally destroyed by Russian attacks.

The theoretical potential for annual production per installed capacity in the different oblast of Ukraine are shown at the map in Figure 26. It only gives an indication of where it could be easier to find good places for hydro power. The realized annual production depends on the specific place.

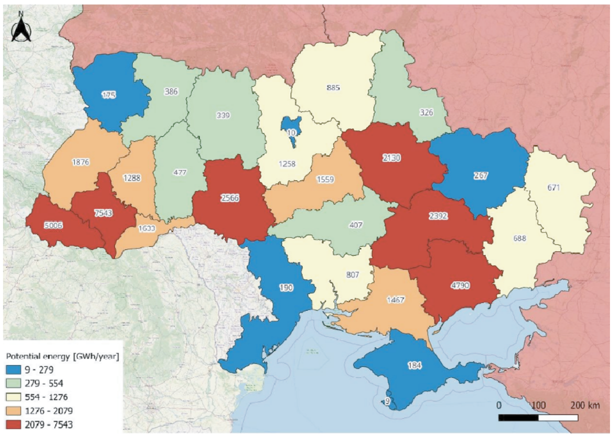



*Figure 26: Hydro power resource chart, expected potential for annual hydro power generation (MWh per MW installed capacity) in different regions of Ukraine. The map is based data from the study Systematic high-resolution assessment of global hydropower potential, 2017*

## 4.8.1. Brief technology description

Hydropower has been a reliable and proven method for electricity production for more than a hundred years.

The hydropower concept exploits the head difference between two water reservoirs, be it natural or artificially created through dams and weirs. In a hydropower plant, the potential energy is converted into rotational kinetic energy, which spins the blades of a turbine connected to a generator.

### 4.8.1.1. Run-of-River (RoR) Hydro Power Plants.

Run-of-river (RoR) hydro power plants is a facility that channels water flowing from a river through a canal or penstock to spin a turbine. Typically, a run-of-river project has little or no storage facility. They are typically small and find applications also in off-grid contexts. A scheme for a RoR hydro power plants is presented in Figure 27 below.

Run-of-river (ROR) hydropower plants are renewable energy facilities that generate electricity by harnessing the natural flow and elevation drop of rivers. Unlike conventional hydroelectric plants, ROR systems typically do not require large dams or reservoirs. ROR plants operate by diverting a portion of the river flow through the penstock, utilizing the elevation difference to generate power. The diverted water is then returned to the river downstream.

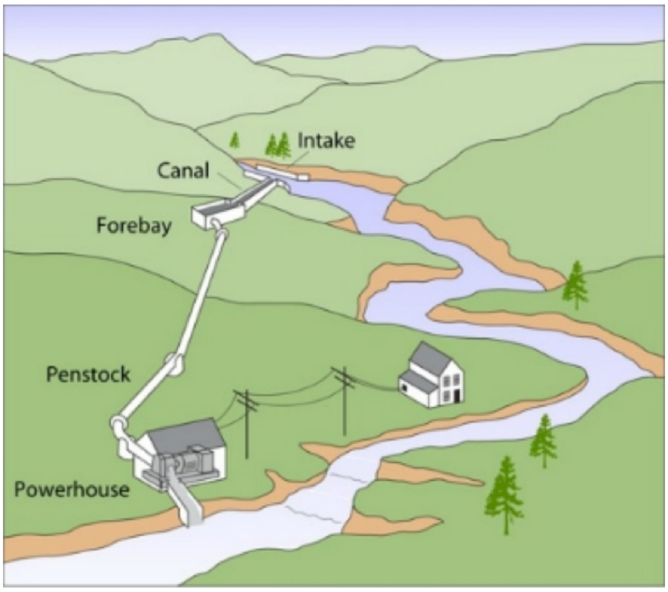



*Figure 27: Run-of-river hydropower plant schematics*

The key components of a ROR hydropower plant include:

Intake structure: A small dam or weir diverts water from the river. It may incorporate adjustable gates for flow control and fish ladders to mitigate ecological impact.

- **Trash rack:** Metal bars spaced 40-100 mm apart filter debris, protecting downstream equipment. Some systems feature automated cleaning mechanisms.
- **Penstock:** A pipeline or channel, often made of steel, ductile iron, or reinforced concrete, carries water from the intake to the powerhouse. Diameters typically range from 1 to 5 meters, with lengths varying based on topography.
- **Powerhouse:** Houses the turbine, generator, and auxiliary equipment. It's designed to withstand flooding and seismic activity.
- **Turbine:** Converts the water's kinetic energy into mechanical energy. Common types include:
  - **Francis turbines:** For medium heads (10-350 m), efficiency up to 95%
  - **Kaplan turbines:** For low heads (<30 m), with adjustable blades
  - **Pelton turbines:** For high heads (>100 m), used in some high-head ROR plants
- **Generator:** Typically, a synchronous type, directly coupled to the turbine, converting mechanical energy into electrical energy.
- **Control system:** Utilizes Programmable Logic Controllers (PLCs) for automated operation and SCADA systems for remote monitoring and control.
- **Transformer:** Steps up voltage for grid connection.
- **Switchgear:** Includes circuit breakers, disconnectors, and protection relays for safe grid integration.
- **Tailrace:** Returns water to the river, designed to minimize erosion and turbulence.

The power output of a ROR plant depends on the flow rate (Q) and head (H), following the equation:

$$\text{Power} = \eta \times \rho \times g \times Q \times H$$

Where η is efficiency, ρ is water density, and g is gravitational acceleration.

ROR systems typically do not require large dams or reservoirs, thereby having lower environmental impact and land use compared to large reservoir systems.

ROR systems typically maintain a minimum ecological flow in the river, often 10-30% of the natural flow rate, to preserve aquatic ecosystems. Advantages of ROR plants include minimal flooding, preserved natural habitats, and resilient.

However, their output is highly dependent on natural river flow, which can fluctuate seasonally.

Modern ROR plants can achieve overall efficiencies up to 90%, with individual components like turbines exceeding 95% efficiency under optimal conditions. These systems play a crucial role in sustainable energy production, offering a balance between power generation and environmental conservation.

### 4.8.1.2. Storage/reservoir Hydro Power Plants

Storage/reservoir Hydro Power Plants uses a dam to store water in a reservoir (water impoundment). Electricity is produced by discharging water from the reservoir through a turbine, which activates a generator. They can span over a wide range of capacities, depending on the hydraulic head and reservoir size.

A scheme for a hydro power plant with dam is presented in Figure 28.

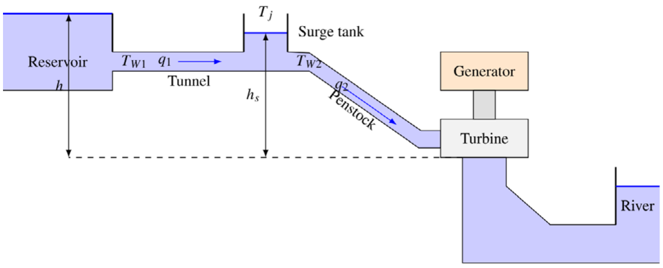



*Figure 28: Reservoir hydropower plant schematic*

Run-of-river and reservoir hydropower plants can be combined in cascading river systems and pumped storage hydro plants can utilize the water stored in one or several reservoir hydro power plants. In cascading system principle (Figure 29), the energy output of a run-of-river hydro power plant can be regulated by an upstream reservoir hydro power plant. A large reservoir in the upper catchment generally regulates outflows for several run-of-rivers or smaller reservoir plants downstream. This likely increases the yearly energy potential of downstream sites and enhances the value of the upper reservoir's storage function. However, this also creates the dependence of downstream plants to the commitment of the upstream plants. Forecasting output from the various cascaded HPPs can be accurate as water flow measurements in the first HPP can be applied in calibrating the forecasting algorithm for all cascading power plants. As water cannot be compressed and a known part is evaporating or diverting the time schedule for the cascading plants can be forecasted accurately. In UA is two different cascading systems, namely, the Dnipro cascade (total of 9 900 MW) and the Dniester cascade (total of 730 MW).

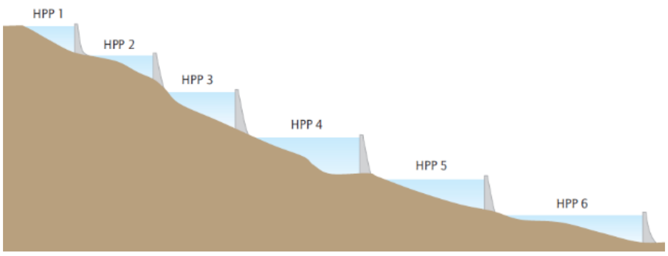



*Figure 29: Cascading System principle*

### 4.8.1.3. Pumped Hydro Storage power plants

Provides peak load supply, harnesses water which is cycled between a lower and upper reservoir by pumps that use surplus energy from the electrical system at times of low demand and low costs. While plenty of pumped hydro storage plants exist and are under construction in the world, Ukraine has few of these facilities. The Kyiv Pumped Storage Power Plant (972 MW), the Dniester Pumped Storage Power Station (1 000 MW), Kyiv Hydroelectric Power Plant (235 MW) and the Tashlyk Pumped Storage Power Plant (302 MW) in total a capacity of 2 509 MW.

A scheme for Pumped Hydro Storage power plants is presented in Figure 30.

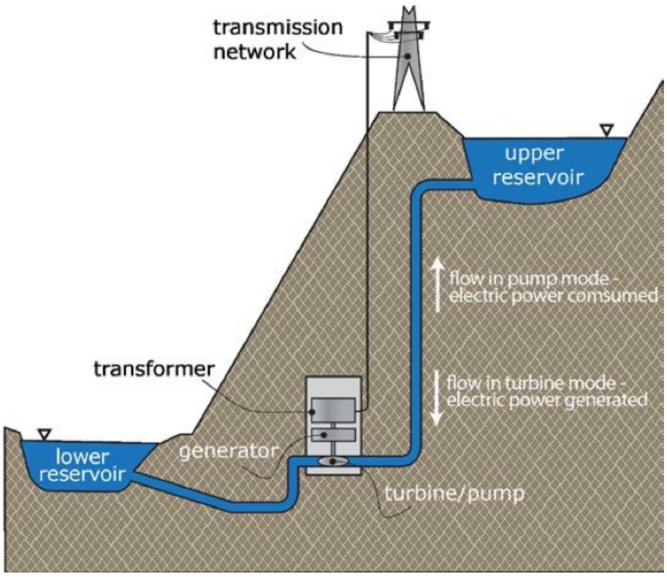



*Figure 30: Pumped Hydro Storage power plant*

Pumped Hydro Storage (PHS) are one of the key balancing means to adapt variable renewable energy resources like solar, wind, and run off river power generation as well as preserving the dynamic stability of the grid system in low demand scenarios, e.g. during nighttime and/or operating the grid system in intentional islanding for increasing the resilience to attacks.

Hydro power plants range from kW to hundreds of MW. A classification based on the size of hydro power plants is presented in Table 39.

*Table 39: International classification of hydropower plants based on capacity size*

| Type | Capacity (international classification) |
|---|---|
| Large hydropower | >100 MW |
| Medium hydropower | 25-100 MW |
| Small hydropower | 1-25 MW |
| Mini/micro hydropower | <1 MW |

Large hydropower plants often have outputs of hundreds or even thousands of megawatts and use the energy of falling water from the reservoir to produce electricity using a variety of available turbine types (e.g., Pelton, Francis, Kaplan) depending on the characteristics of the river, the hydraulic head, and installation capacity. Small, micro hydropower plants are run-of-river schemes. These types of hydropower use Crossflow, Pelton, or Kaplan turbines.

For high heads and small flows, Pelton turbines are used, in which water passes through nozzles and strikes spoon-shaped buckets arranged on the periphery of a wheel. A less efficient variant is the crossflow turbine. These are action turbines, working only from the kinetic energy of the flow.

For low heads and large flows, Kaplan turbines, a propeller-type water turbine with adjustable blades, dominate. Kaplan and Francis turbines, like other propeller-type turbines, capture the kinetic energy and the pressure difference of the fluid between entrance and exit of the turbine. Francis turbines are the most common type, as they accommodate a wide range of heads (20 m to 700 m), small to very large flows, a broad rate capacity and excellent hydraulic efficiency.

The selection of the turbine type depends on the net head defined on Figure 31 and the flow rate of the river.

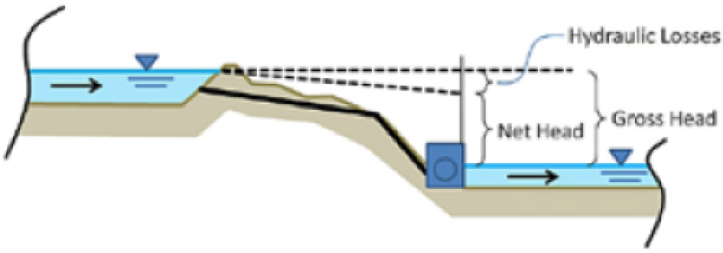



*Figure 31: Hydro Power – definition of net and gross head*

The hydropower turbine application chart related to the net head and the flow rate of the river is depicted in Figure 32.

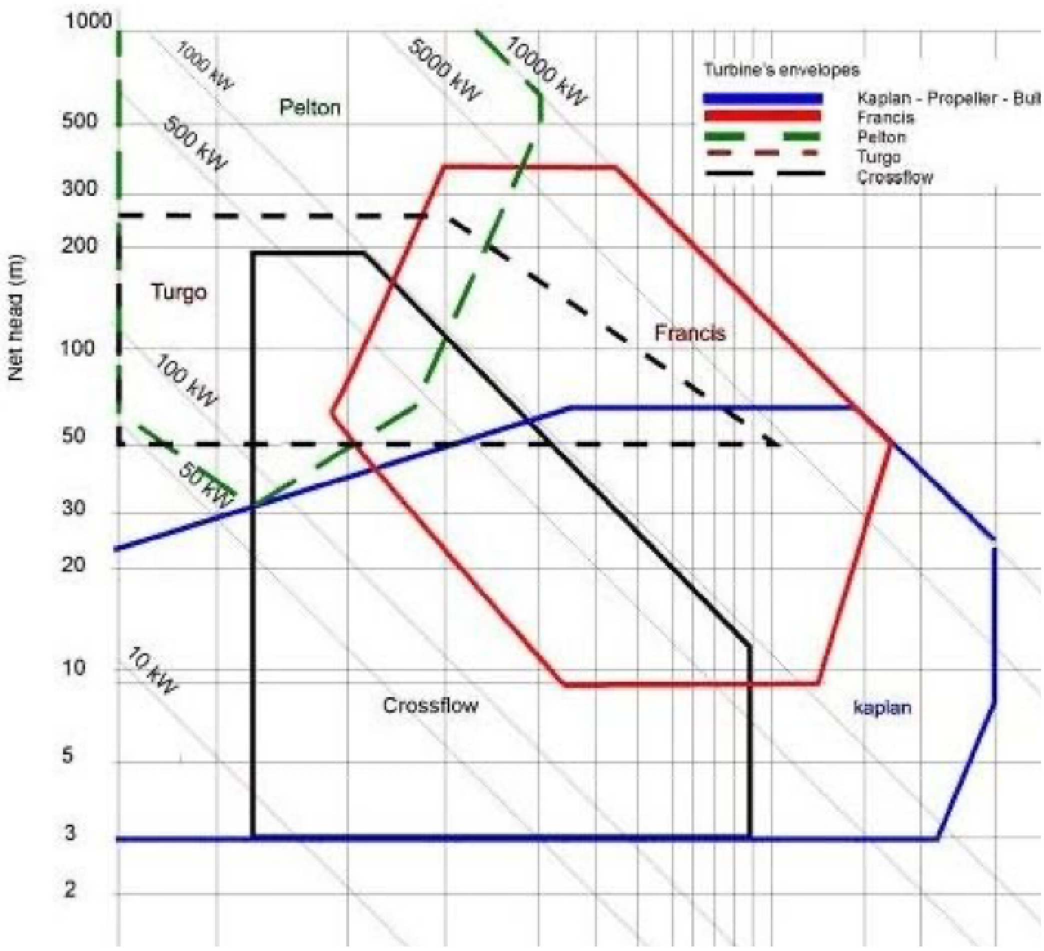



*Figure 32: Hydropower turbine application chart*

The capacity factor achieved by hydropower projects needs to be looked at somewhat differently than for other generation projects. It depends on the availability of water and the purpose of the plants whether for meeting peak and/or base demand. The average capacity factor of hydropower plants settled at 48% in 2010-2019 (world-wide figures), with a significant standard deviation across geography. The blue areas in the figure represent the standard deviation from the average (Figure 33).

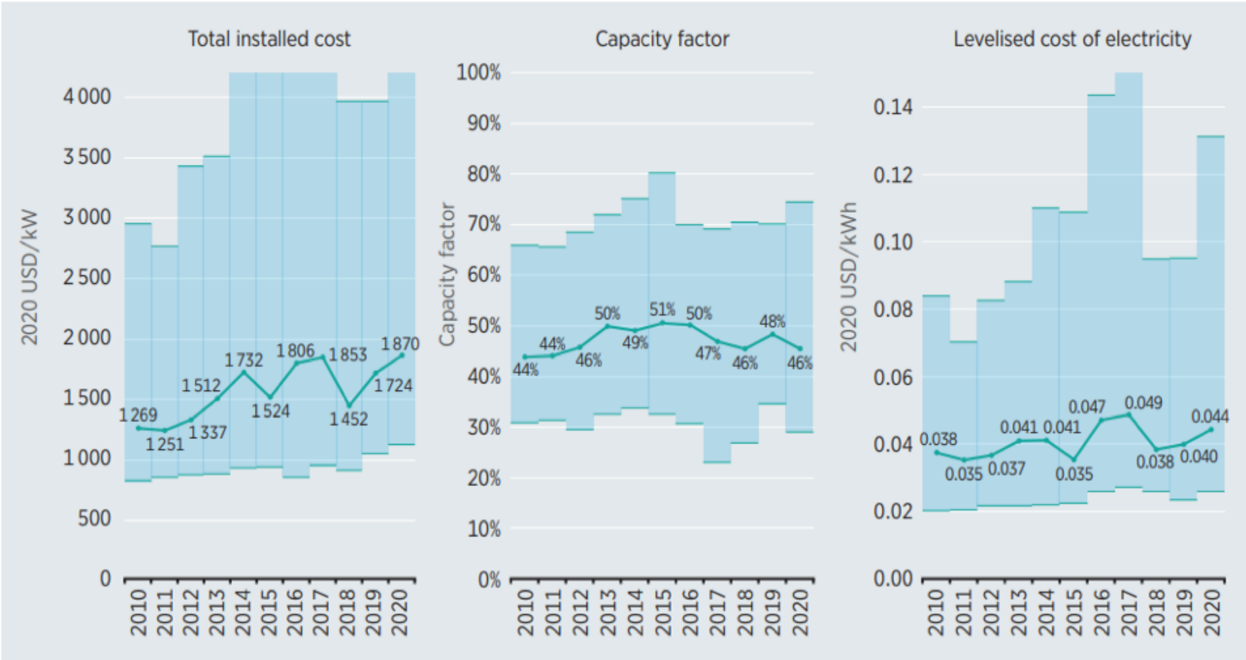



*Figure 33: Total inst. cost, capacity factor, LCOE for hydropower (world). The results are primarily based on data for large hydropower plants (HPPs) and include pumped storage*

Table 40 presents a partial list of large hydropower plants (HPPs) and pumped storage hydroelectricity stations (PSHs) currently operating in Ukraine, according to Ukrhydroenergo. As a note, the turbine technology is indicated.

*Table 40: List of hydro power plants in UA HPP: Hydro Power Plant with dam; PHS: Pump Hydro Storage Power Plant; RoR: Run-of-River (without a dam) – variable like wind and solar*

| Name | Location | Technology | Power (MW) | Year built | Note |
|---|---|---|---|---|---|
| Dnieper Hydroelectric Station | Zaporizhzhia | HPP | 1 548 | 1927-1939; 1969-1980 | Francis |
| Dniester Hydroelectric Power Plant | Novodnistrovsk | HPP | 702 | 1973-1981 | Kaplan |
| Dniester Pumped Storage Power Station | | PHS | 972 | 1983-2015 | Francis |
| Kyiv Hydroelectric Power Plant | Vyshhorod | HPP | 388.8 | 1964 | Bulb |
| Kyiv Pumped Storage Power Plant | | PHS | 235 | 1970 | Francis |
| Kaniv Hydroelectric Station | Kaniv | HPP | 444 | 1972 | |

| | | | | | |
|---|---|---|---|---|---|
| Kaniv Pumped Storage Power Station | Buchak, Kaniv [uk] | PHS | 1 000 | 1986-1991; 2019-? (under construction) | |
| Kremenchuk Hydroelectric Station | Svitlovodsk | HPP | 625 | 1959 | Propeller |
| Kakhovka Hydroelectric Station | Nova Kakhovka | HPP | 351 | 1950-1956 | Propeller<br>Destroyed 6 June 2023 |
| Middle Dnieper Hydroelectric Power Plant | Kamianske | HPP | 352 | 1963 | Propeller |
| Tashlyk Pumped Storage Power Plant | Pivdennoukrainsk | PHS | 302 | 1981-2007 | Francis |

## 4.8.1.4. Retrofit of HPPs with dams and pumped hydro storage

Retrofitting and/or upgrading of existing hydropower facilities have a lot of quick wins and a series of low hanging fruits to be harvested. The following quick wins among others can be mentioned:

- The facilities are already grid connected
- The facilities are already commissioned and operative
- The facilities are already staffed
- All operational and security procedures are in place
- Information exchange and data communications aspects are already in place

Retrofitting existing facilities can be very attractive in time for implementation as well as limited involved cost.

## 4.8.2. Criteria evaluation – hydropower

This section covers the selected criteria for evaluation of hydropower, which are intended for use as a guidance for selecting the most appropriate generation technology in the actual situation.

*Table 41: Criteria evaluation matrix of hydro power plants*

| Criteria evaluation | 8.a. Hydro, RoR, small | 8.b. Hydro, RoR, micro | 8.c. Retrf Hydro power, dams incl. PHS |
|---|---|---|---|
| Winter impact | WW | WW | WW |
| Implementing speed | Q | Q | QQ |
| Resilience | RRR | RRR | R |
| Cost (LCOE, wintertime 2 years lifetime) | CC | CC | n.a |
| General score (1-3) | 1.6 | 1.8 | n.a |
| General scores (excl. cost) (1-3) | 1.8 | 1.8 | 2.0 |

The criteria evaluation is based on the parameter evaluation in the section below.

**Winter impact (production at wintertime)**

Hydro Power Plants can contribute to the Ukrainian power system during wintertime as long as the minimum required water stream is available. Small run-of-river (RoR) hydro plants struggle more in winter due to frozen or insufficient water flow, than larger hydro plants with dams, which can better manage seasonal variations, maintaining production through stored water.

HPPs with dams can regulate their generation allowing them to produce at full capacity during wintertime and add essential stability services as well as system inertia inherently provided by the synchronous generator technology.

Most of the micro hydro generators are based on non-synchronous technology and, as such, are lacking the capability for providing some of the stabilizing services as well as adding value to the system inertia.

Nearly all hydropower generators with a nominal capacity above 1 MW are based on synchronous technology and, as such, have the built-in capability to provide the minimum required stabilizing services as well as contributing to the system inertia.

Retrofitting the existing hydropower facilities might be required to provide the required frequency service capability.

**Implementing speed**

The timeline for the implementation of a hydro power plant is highly dependent on the facility size.

The implementation of greenfield small and mini/micro-scale run-of-river (RoR) HPPs is assumed to take longer than the retrofitting of existing HPPs with dams and PHS facilities due to the extended time required for planning and regulatory approvals for the green field plants. In the parameter evaluation, the small and mini/micro-scale RoR HPPs have an estimated project time of 130 weeks. The estimated project time for retrofitting large HPPs with dams and PHS is 70 weeks. The variability of the estimated project time can be significant as local issues and supply chain challenges can vary from area to area and time to time.

**Resilience**

In general, the resilience of the small and mini/micro RoR HPPs is assessed to be **good**, while the resilience of the large HPPs with dams (incl. PHS) is assessed to be **poor**.

RoR scores high among other things because it’s a small capacity that is taken out of operation at once, while the small capacity also makes them less interesting to attack. Whereas the large HPPs score **poorly** for the same reasons.

The resilience of hydro power plants is also linked to local issues of the topology of the water stream and the landscape. If the hydropower generators can be dispersed into smaller units and hidden along the water stream and be able to deliver a combined sizeable production capacity, it will increase the resilience of the complete facility.

Using underground cabled wiring to transmit the power from the facility instead of overhead lines will also increase the resilience against aggressive attacks and sabotage.

**Generation costs (LCOE), short term (winter production) and over the lifetime**

In comparison to the other evaluated technologies, the LCOEs for winter production over 2 years for small and mini/micro RoR HPPs are close to average for all the included technology types, thus assessed as medium. 98% of the LCOE cost is due to financial and investment cost.

Contrary, the LCOEs over the lifetime for the RoR HPPs are below 25% of average for LCOE of for all the included technology types. The hydro plants perform better over their lifetime because there is no cost for fuel, and OPEX is moderate.

Regarding the retrofitting of large HPPs with storage including PHSs, LCOE calculations have not been performed due to insufficient available data. However, a global LCOE evolution through 2010-2020 for HPPs are depicted in Figure 33, it shows that the LCOE for HPPs are low compared to the lifetime LCOEs calculated for RoR HPPs.

## 4.8.3. Parameter evaluation – hydro power

This section covers the parameter evaluation of hydropower, which is used as the basis for the criteria evaluation.

*Table 42: Parameter evaluation matrix of hydro power plants*

| Criteria evaluation | 8.a. Hydro, RoR, small | 8.b. Hydro, RoR, micro | 8.c. Retrf Hydro power, dams incl. PHS |
|---|---|---|---|
| P1-Electricity production at wintertime | 40% | 40% | 70% |
| P2-Levelized Cost of Electricity (LCOE) short lifetime, winter production [€/MWh] | 1790 | 1503 | n.a. |
| P3-Levelized Cost of Electricity (LCOE) over lifetime [€/MWh] | 54 | 47 | n.a. |
| P4-Distributed generation | Good | Good | Poor |
| P5-Regulation requirement in the project development process | Lengthy | Lengthy | Quick and easy |
| P6-Delivery time and availability of components and materials | In between | In between | In between |
| P7-Requirements for logistics and transportation infrastructure | Low | Low | Medium |
| P8-Technical installation time (after clearance) | Lengthy and complicated | Lengthy and complicated | Medium-term |
| P9-Requirements for skilled staff in construction phase | Medium | Medium | Medium |
| P10-Grid balancing capacity | High | Low | High |
| P11-Requirements for electricity grid infrastructure | Easy | Easy | Easy |
| P12-Requirements for skilled staff for operation and maintenance and for special spare parts | Low | Low | Low |
| P13-Possibility for camouflage and sheltering | Medium | Medium | Low |
| P14-Risk associated with fuel supply | Low risk | Low risk | Low risk |
| P15-Restoration time | In between | In between | In between |

**P1: Electricity Production at Wintertime (W)**

The potential for generating electricity from hydropower in Ukraine during the winter months (October to March) varies significantly by region. The peak electricity generation periods are in spring and autumn. Spring brings floods and snowmelt. Autumn is also productive due to heavy rainfall and increased water availability.

Hydro Power Plants can contribute to the Ukrainian power system during wintertime as long as the minimum required water stream is available and that the stream is not totally frozen. Small run-of-river (RoR) hydro plants struggle more in winter due to frozen or insufficient water flow, than larger hydro plants with dams, which can better manage seasonal variations, maintaining production through stored water.

Therefore, it is estimated that the small and mini/micro RoR hydro plants can deliver around 40% of the capacity during the wintertime. While HPPs can regulate their generation allowing them to produce at least 70% of full capacity during wintertime and add essential stability services as well as system inertia inherently provided by the synchronous generator technology.

**P2: Levelized Cost of Electricity (LCOE) short lifetime, winter production (C)**

The Levelized Cost of Energy (LCOE) short lifetime, winter production (C) for run-of-river (RoR) hydropower plants is estimated as follows:

- For small RoR hydropower plants: approximately €1 800/MWh
- For micro/mini RoR hydropower plants: approximately €1 500/MWh

Financial[27] costs and CAPEX are completely dominant, accounting for 56% and 42% of LCOE respectively, while OPEX only accounts for about 2%.

In comparison to the other evaluated technologies, the LCOE over 2 years of wintertime production for the RoR hydropower plants are evaluated **medium**[28].

Regarding the retrofitting of large HPPs with storage including PHSs, LCOE calculations have not been performed due to insufficient available data.

**P3: Levelized Cost of Electricity (LCOE) over lifetime (C)**

The Levelized Cost of Energy (LCOE) over the lifetime for run-of-river (RoR) hydropower plants is estimated as follows:

- For small RoR hydropower plants: approximately €55/MWh
- For micro/mini RoR hydropower plants: approximately €50/MWh

The costs are divided almost equally into financial costs (40%), CAPEX (30%) and OPEX (30%).

In comparison to the other evaluated technologies, the LCOE over the lifetime for the RoR hydropower plants is evaluated **good**[29]. The hydro plants perform better over their lifetime because there is no cost for fuel, and OPEX is moderate.

Regarding the retrofitting of large HPPs with storage including PHSs, LCOE calculations have not been performed due to insufficient available data.

However, examples of calculations of LCOE evolution for the through 2010-2020 for HPPs are depicted in Figure 33. The results are primarily based on data for construction of large hydropower plants (HPPs) and include PHS. It is shown that the LCOE is around 50-60% of the LCOE for the RoR HPPs. This could indicate that the refurbishment of the HPPs and PHSs could be assumed to be **good**.

**P4: Distributed generation (R)**

Mini/micro run-of-river (RoR) hydropower plants and small RoR HHPs are defined (according to the international classification) as having capacities of less than 30 MW and 1 MW, respectively. Evaluating their potential to

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27 10% discount rate assumed for all LCOE calculations

28 Between 25% lower than average and 25% higher than average, the average is app. 1 525 €/MWh

29 Good: more than 25% lower than average, average for LCOE over lifetime is 120€/MWh

be located near demand centres, it is evident that their placement is somewhat limited due to the necessity of a river with significant flow and height difference. However, when these natural conditions are met, it is feasible to situate mini/micro and small RoR HPPs close to demand areas, even within a city. Therefore, the Distributed Generation parameter is set to **good** for Mini/micro and small RoR HPPs.

Conversely, for hydropower plants with dams and pumped hydroelectric storage (PHS), the parameter "distributed production" is assessed to be **poor**, because the capacity for this type of hydropower plant is typically far above 60 MW, thus a large capacity could be taken out of operation by a single incident.

This reflects that in general, smaller distributed units are more resilient than large, centralized units. Several examples of the high risk with large centralized system can be given, e.g., the captivity of the Zaporizhzhia NPP facility and the sabotage of the Kakhovka HPP facility in 2023. Globally a long list of high risks related to large generation facilities could be mentioned. That's why a more distributed approach is recommended in UA with an increase in resilience as the outcome.

**P5: Regulation requirement in the project development process (Q)**

The following describes the process preceding the commencement of construction of hydropower plants in Ukraine, as well as the regulations that must be met before the construction of hydropower plants of all sizes can begin. Based on these descriptions, it is estimated that the periods for obtaining permits are 52 weeks for small and mini/micro RoR HPPs. For the restoration and improvement of large HPPs with dams and PSHs, it is assessed that permits can be obtained significantly faster, and the period is therefore set at 12 weeks.

Thereby, the P5-Regulation Requirement in the project development process (Q) is accessed to be **lengthy and complicated** for small and mini/micro RoR HPPs and **quick and easy** for restoration and improvement of large HPPs with dams and PSHs.

The project development process begins with a site visit and assessment, followed by preparing a feasibility study (FS). This study includes equipment selection, cost calculations, annual electricity production estimates, and technical parameters. Once the FS is complete, the entity formalizes the land plot, which involves legal and administrative steps to secure the land for the project.

The next critical step is the Environmental Impact Assessment (EIA). This process evaluates the potential environmental effects of the project and is essential for obtaining necessary approvals. However, this is where bottlenecks often occur. Even if the land plot is leased and preliminary public discussions have been held, obstacles can arise during the EIA process. If the locals perceive no immediate gain, they may oppose the construction, leading to significant delays.

This issue is particularly prevalent in the western regions of Ukraine, where local opposition can be strong. As a result, many clients, despite having already leased the land plot, find themselves unable to move the project forward. This opposition during the EIA stage is a significant problem that can halt the entire development process.

The Law of Ukraine "On Strategic Environmental Assessment" is applicable for a hydropower project of any size. Additionally, the Environmental Impact Assessment (EIA) process is a critical step for obtaining necessary permits. The Environmental Impact Assessment (EIA) process is identified as a critical and potentially problematic step in the project development process, often leading to delays due to local opposition.

For grid connection, the UA implementation of the EU grid connections network code for all generators according to the EU 631/2016 shall apply to all new installations.

For facility operation the UA implementation of the EU regulation for transmission system operational guideline Commission Regulation (EU) 2017/1485 and the Network code for Emergency and Restoration, the EU 631/2016 shall apply to all new installations.

For market operation, the UA implementation of the Commission Regulation (EU) 1222/2015 of 24 July 2015 establishing a guideline on capacity allocation and congestion management and the FCA – the UA implementation of the Commission Regulation (EU) 2016/1719 of 26 September 2016 establishing a guideline on forward capacity allocation end the EB guideline the UA implementation of the Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing shall apply to all new installations.

From this, it is estimated that the periods for obtaining permits are 48, 26, and 52 weeks for respectively small and micro RoR hydro power plants and hydro power w. dams and PHS.

**P6: Delivery time/availability of components and materials (Q)**

Delivery Time/Availability of Components and Materials (Q) are assessed to be **medium** for all types of HPPs and PHSs included in this report.

The delivery time of all components and materials, for construction on green field of hydro power plant, is expected to be approximately 40 weeks from the initial purchase date. This is partly because there is an ongoing supply chain shortage for electrical components.

For retrofit, it is expected that only some components will be newly produced, and this varies between the plants. So, in general it is expected to take 30 weeks to source the components for refurbishment of HPPs and PHSs.

There's one Ukrainian company producing components for HHPs and PHSs located in Kharkiv.

**P7: Requirements for logistics and transportation infrastructure (Q)**

The transportation of components for the hydro power plant does to some extent require transportation by train, boat, or special vehicles, equipment, or routes. The logistics and transportation infrastructure in Ukraine may pose some challenges due to poor road conditions in some areas, damages to railways, ports and cranes, and security risks in war areas.

Railways and the ports have been heavily damaged, and shipments that used to come through the Black Sea have become nearly impossible.

This means that the refurbishment or repair of HPP have **medium** evaluations for the need for logistics and transportation infrastructure. While small mini/micro RoR HPP is given the best evaluations for the need for logistics and transportation infrastructure.

Ensuring access to adequate transport infrastructure may be a critical parameter in the process of identifying sites for HPPs, especially for not micro scale plants.

**P8: Technical installation time (min time after clearance) (Q)**

The installation time for the hydropower plants is expected to be around 40 weeks for construction of small and mini/micro RoR HPPs and around 30 weeks for refurbishment of HPPs with dams and PHS. Thus, P8 are assessed respectively, **lengthy, and complicated and medium-term.**

**P9: Requirements for skilled staff in construction phase (Q)**

In the construction phase, for most of the staff no special requirements are required except for all skills for building and construction according to the current UA legislation. However, there is a limited request for specialized designers and engineers, and it could be hard to find these in the current situation. Thus, the parameter is assessed to be **medium** for all HPPs and PHSs.

**P10: Grid balancing capability (R)**

The Grid balancing capacity is assessed to be **low** for mini/micro RoR, **medium** for small RoR, and **high** for large HPPs and PHSs, the explanation for the assessments can be found in the text below.

All minimum grid connection requirements for functionality and parameter ranges are stated in the UA implementation of the EU grid connections network code for all generators according to the Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators.

HPPs with dams and PHS can regulate their generation and thereby add essential stability services as well as system inertia inherently provided by the synchronous generator technology.

Most of the micro hydro generators are based on non-synchronous technology and as such are lacking the capability for providing some of the stabilizing services as well as adding value to the system inertia.

Nearly all hydropower generators with a nominal capacity above 1 MW are based on synchronous technology and as such have the built-in capability to provide the minimum required stabilizing services as well as contributing to system inertia.

Hydropower generation facilities with modern control capability are normally able to provide Frequency Containment Reserve services (FCR) as well as Frequency Restoration Reserve services (FRR) and Replacement Reserve services (RR). Retrofitting the existing hydropower facilities might be required to provide the required frequency service capability.

**P11: Requirements for electricity grid infrastructure (R)**

Hydropower plants of mini/micro and small-scale have a moderate electricity generation capacity. Therefore, the requirement for the electricity grid infrastructure is **low**, as these plants can be connected to the distribution grid system at the medium voltage level. Voltage levels are not essential for grid stability, so if a transmission line is passing the hydropower facility, it can be connected to the transmission grid system if it fulfils the minimum connection requirements in the UA implementation of the EU grid connections network code for all generators according to the EU regulation 631/2016. For the refurbishment of large HPPS and PHS the requirement for the grid infrastructure has also been assessed to be **low** because it is assumed that existing infrastructure can be used even if the production from the HPPs or PHSs is increased.

In the interviews it is also described that there are no significant hurdles in the connection process. The process of connecting to the grid is relatively simple. In 2007-2010, a Cabinet of Ministers resolution required regional energy companies (Oblenergo) to connect all small hydropower plants. For example, several HPPs have been built in the Kirovohrad region, and Kirovohrad Oblenergo extended a 10 kV line to these plants. The process is clear: approach the regional energy company, submit an application specifying the required capacity, pay the connection fee (now standardized), and then build the line and the station. There are no significant hurdles in the connection process.

**P12: Requirements for skilled staff for operation and maintenance and for special spare parts (R)**

No special requirements for the staff for the daily operating of hydropower facility except an understanding of the operational concept and a required qualification according to the UA implementation of the EU regulation for transmission system operational guideline Commission Regulation (EU) 2017/1485 and the Network code for Emergency and Restoration.

**P13: Possibility for camouflage and sheltering (R)**

The resilience of hydro power plants is linked to local issues of the topology of the water stream and the landscape. If the hydro power generators can be dispersed into smaller units and hidden along the water stream and then being able to deliver a combined sizeable production capacity, it will increase the resilience of the complete facility.

In case the landscape provides natural bunkering of large parts of the hydro power plant the resilience will be increased as well.

In general, it is not possible to shelter or camouflage the large HPPs. However, using underground cabled wiring to transmit power from the facility instead of overhead lines will also increase resilience against aggressive attacks and sabotage.

Thus, the possibility of camouflage and sheltering are assessed to **medium** for the small and mini/micro RoR HPPs. Contrary, the possibility is assessed to be **low** for the large HPPs and PHSs.

**P14: Risk associated with fuel supply (R)**

For the HPPs, it is assumed that the risk for hostile cutting off of the water supply is assessed to be **low**. For example, the UA river systems of Dnieper as well as Dniester are collecting water from diversified areas with a large topographical variation the water level available for the various HPPs is evaluated not to have a big diversity, so the risk that the water supply is cut off is low. In addition, requirements for farming irrigation bindings are neglectable or do not exist. So, in conclusion, the fuel supply for hydropower does exist all year round.

An example of the rich water resources of the Dniester Hydro Power Complex with more than 15 rivers providing water for the generation facilities is depicted in Figure 34.

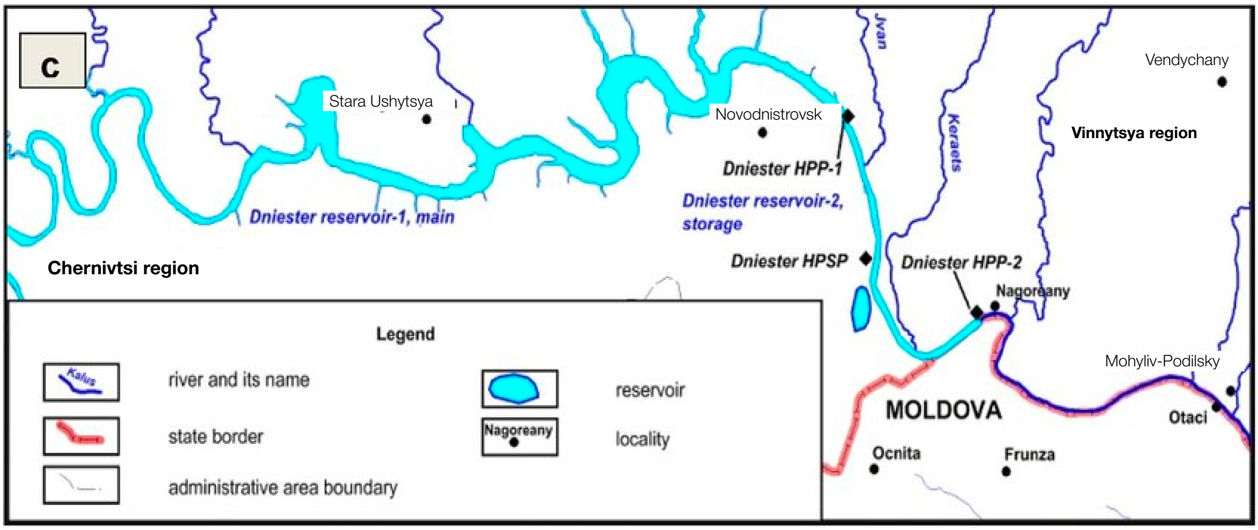


*Figure 34: Dniester Hydro Power Complex*

Another example of the very rich water resources is the Dnieper River system.

More than 89 rivers are providing water for the Dnieper River basin and the Dnieper Cascading System with 6 HPPs involved. The Dnieper River dams and cascading system are depicted in Figure 35.


*Figure 35: Dnieper River dams and cascading system*

**P15: Restoration time**

Restoration time for hydropower is generally perceived as the same as total delivery and installation time. However, for some damages, it will be significantly faster to restore operations. Thereby the Restoration time are assessed to medium.

## 4.8.3.1. Data sheet

In Appendix F.

# List of Abbreviations

| Abbreviations | Definitions |
|---|---|
| € | Euro |
| AC | Alternating current |
| BOS | Balance of system |
| CAPEX | Capital expenditure |
| CBRM | Close-range ballistic missiles |
| CCGT | Closed Cycle Gas Turbine |
| CHP | Combined Heat and Power |
| $CO_2$ | Carbon dioxide |
| DC | Direct current |
| EIA | Environmental impact assessment |
| ESCO | Energy service companies |
| ESS | Energy storage systems |
| FGT | Flue gas treatment |
| FLH | Full load hours |
| GW | Gigawatt |
| HPP | Hydro Power Plant |
| HPP | Hydroelectric Power Plant |
| HPP – PHS | Hydro Power Plant – Pump Hydro Storage |
| HPP – RoR | Hydro power Plant – Run-of-River |
| HVAC | Heating, ventilation, and air conditioning |
| IBRD | International Bank for Reconstruction and Development |
| IEC | International Electrotechnical Commission |
| IEV | International Electrical Vocabular (IEC standard) |
| IFC | International Finance Cooperation |
| kg | Kilogram |
| kW | Kilowatt |
| kWe | Kilowatt electric |
| kWh | Kilowatt-hour |

| | |
|---|---|
| LCOE | Levelized Cost of Electricity |
| LIB | Lithium-ion batteries |
| LTE | Lifetime extension |
| m | Meter |
| $m^2$ | Square meter |
| MoE | Ministry of Energy |
| MW | Megawatt |
| MWe | Megawatt electric |
| MWh | Megawatt-hour |
| MWp | Megawatt power |
| MWth | Megawatt thermal |
| NEURC | National Energy and Utilities Regulatory Commission (NEURC) |
| NG | Natural gas |
| NOx | Nitrogen oxides |
| O&M | Operation and maintenance |
| OPEX | Operating expenses |
| ORC | Organic Rankine cycle |
| OCGT | Open Cycle Gas Generator |
| P1, P2, etc. | Parameter 1, Parameter 2, etc. |
| PCED | Project and Cost Estimate Documentation |
| PHS | Pumped Hydro Storage |
| PJ | Petajoule |
| PPA | Power Purchase Agreement |
| PV | Photovoltaics |
| Q | Implementing speed (how quick this could be done) |
| R | Resilience of selected technologies |
| RoR | Run-of-River – Hydro Power Plant |
| s | Second |
| SCR | Selective Catalytic Reduction |
| TEFS | Technical and Economic Feasibility Study |
| TMS | Thermal Management System |
| TPP | Thermal Power Plant |
| TPP-G | Thermal Power Plant – gas fired |
| TPP-C | Thermal Power Plant – coal fired |
| TSO | Transmission system operator |

| | |
|---|---|
| UA | Ukraine, Ukrainian |
| UDEPP | Ukraine-Denmark Energy Partnership Programme |
| UNDP | United Nations Development Programme |
| UPS | Uninterruptible power supply |
| VRE | Variable energy resources |
| W | Watt |
| W | Winter impact |
| Wh | Watt-hour |
| WtE | Waste to Energy |
| WTG | Wind Turbine Generator |
| WTGS | Wind Turbine Generator System (IEV definition) |

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9. Appendix A

# Methodology

## 9.1. Description of the 15 parameters and how they are evaluated

The following subsections will delve into the underlying reasons for addressing each parameter in this technology catalogue and how they influence the implementation of power generation projects in the current Ukrainian context. Following this, we will explore the three-level assessment scale specific to each of these parameters.

### 9.1.1. P1: Electricity production capacity in wintertime (October to March)

The parameter "electricity production capacity at wintertime" (P1) assesses the capability of a technology to produce electricity during the winter half-year, spanning October through March (inclusive), which comprises 4 368 hours. This parameter evaluates how much of the technology's maximum production capacity can be utilized within this period.

Winter electricity generation is a key focus of this technology catalogue, as electricity demand in Ukraine is significantly higher during the colder months because of the increased demand for, e.g., light and heating. And the electricity supply is essential for critical functions. Ensuring adequate electricity supply during winter is vital and more challenging compared to summer.

Technologies with limited capacity to generate electricity in winter, such as solar power, require supplementary generation systems to fill the gap. Reduced winter output, whether due to fuel shortages or intermittent availability of resources, places additional pressure on the energy system to maintain firm capacity and ensure a reliable power supply.

The assessment of this parameter uses a qualitative three-level scale to categorize each technology's potential for winter electricity generation:

- **Good:** High potential. The technology can achieve more than 75% of its maximum technical capacity during the winter half-year. This level is ideal.
- **Medium:** Moderate potential. The technology can achieve between 40% and 75% of its maximum technical capacity during the winter half-year.
- **Poor:** Low potential. The technology can achieve less than 40% of its maximum technical capacity during the winter half-year.

## 9.1.2. P2: Levelized Cost of Electricity (LCOE) short time and winter production and P3: LCOE over the technical lifetime and total production

LCOE is used for assessing the value of the technology to be able to evaluate the cost efficiency of installing the technology.

Two different LCOEs are calculated for each sub-technology:

1. LCOE short time and winter production. LCOE is calculated for production over the lifetime and only for production in wintertime. The cost of the $CO_2$ emissions is not included in these calculations.
2. A general LCOE calculated over the full lifetime and for full lifetime production.

Because of the current situation in UA, it is valuable to know the cost efficiency in the critical situation. Here it is the production at wintertime that is crucial, and the technology is set up knowing that it will maybe only be operating for 2 years. There is also a chance that the technology will be in operation for its full lifetime; therefore it is also interesting to analyse the LCOE over the full lifetime.

Levelized Cost of Electricity (LCOE) is used for assessing and comparing unit cost (€/kWh) of generating electricity using different technologies. The calculation of the LCOE is based on the equivalence of the present value of the sum of discounted revenues and the present value of the sum of discounted costs. LCOE considers all costs associated with building, operating, and maintaining a power generation plant over its expected lifetime or another defined period. The LCOE calculations are described in detail in Appendix B.

The LCOE is a qualitative parameter and is used for assessing the technologies on a three-level scale, the thresholds will be defined according to the distribution of the plants included, and will differ between the short time winter production LCOE and the lifetime LCOE:

- **Good:** Technologies with low LCOE, more than 25% lower than average; **preferred**.
- **Medium:** Technologies with medium LCOE within a range of 25% below to 25% above the average.
- **Poor:** Technologies with high LCOE, more than 25% higher than average.

A $CO_2$ cost of €80/ton is considered in the LCOE calculations corresponding to the current (Ultimo January 2025) price of $CO_2$-allowances in the EU ETS[30].

## 9.1.3. P4: Distributed generation

The parameter “applicable for distributed operation” evaluates a technology’s suitability for deployment at a distributed scale, taking into account its size, both capacity and area uptake, modular design, and the ability to be located near demand centres. This capability is particularly critical under the current conditions in Ukraine, where distributed technologies can mitigate the risks associated with centralized power generation.

The ongoing war has resulted in targeted attacks on power plants, substations, and grid infrastructure, causing widespread power outages. Distributed technologies offer several advantages under these circumstances:

- **Proximity to demand:** They can be located close to consumption centres, reducing dependency on vulnerable transmission grids.

30 https://tradingeconomics.com/commodity/carbon

- **Modular design:** Smaller, modular units are easier to deploy and maintain, offering flexibility in system design and resilience.
- **Risk mitigation:** The strategic interest in targeting a power plant is influenced by the capacity it provides. Smaller, distributed units reduce the impact of any single attack.

This parameter is assessed on a three-level scale that reflects the typical size and deployment flexibility of each technology:

- **Good:** Technologies with capacities below 5 MW are preferred for distributed operation due to their small size. Further modularity and ease of placement near demand centres are considered essential for a technology to receive the grade good in this category; **preferred**.
- **Medium:** Technologies with capacities between 5 MW and 20 MW are moderately suitable for distributed operation, offering a balance between scalability and proximity.
- **Poor:** Technologies with capacities between 20 MW and 60 MW are less suitable for distributed operation due to their larger size and reduced flexibility in placement.

## 9.1.4. P5: Regulation requirement in the project development process

Before the actual construction of the power generation technology can begin, it may in many cases be necessary to obtain permits, conduct comprehensive environmental studies, and perform various assessments such as soil analysis, solar radiation evaluation, and wind condition examinations. Thereafter, financing agreements must be secured. All in all, this can lead to significant time consumption. Furthermore, in general, the UA implementation of the EU requirements for all generators must be followed.

These sequential tasks significantly influence the overall timeline from project conception to commission. Hence, it is essential to develop a comprehensive timeline that outlines the anticipated duration required for these processes.

This parameter is assessed on a three-level scale, assessing the speed and the simplicity of the process under:

- **Good:** quick and easy process, less than three months; **preferred**.
- **Medium:** in between process, between three months and 9 months.
- **Poor:** lengthy and complicated process, more than 9 months.

## 9.1.5. P6: Delivery time/availability of components and materials

The delivery time and availability of power plant components are crucial for quick installation. Therefore, it is crucial to account for the availability of the required technology, components, and materials (e.g., steel and cement) when considering the timeframe on constructing power generation plants.

Essential materials such as steel and cement may be scarce and compete with defence-related purposes for their use in the installation of power-generating technologies.

The time for manufacturing the component or the whole plant of the technology impacts the delivery time, but the capacity to manufacture plants and components for Ukraine may be limited by a high demand in general.

Some systems and components for systems are only produced on demand and are not available in stock. But the delivery time can be considerably reduced if a storage of already produced components or plants exists (which, e.g., is the case for PV modules) or it is possible to buy second-hand plants. In the same way, it could be possible to reduce the delivery time considerably for components, e.g., transformers and inverters if it is possible to obtain some that are produced for another purpose produced for another purpose.

This parameter is assessed on a three-level scale, assessing the delivery time and the availability of the required components and material. For this scope of technology catalogue, technologies with less delivery time are favoured.

- **Good:** delivered within less than 3 months; **preferred**.
- **Medium:** delivered within between three months and 14 months.
- **Poor:** delivered in more than 14 months.

## 9.1.6. P7: Requirements for logistics and transportation infrastructure

War conditions affect the transportation infrastructure to a great extent, therefore technologies with less requirements for transportation infrastructure are highly valuable.

For transporting construction materials and project components, a domestic transportation infrastructure is needed, which may involve roads, railways, ships, etc. This infrastructure is essential for moving both imported and domestically sourced materials and components to power project sites.

This qualitative parameter is assessed on a three-level scale, assessing the dependency on transportation infrastructure as:

- **Good:** low infrastructure demand: the size and the weight of the modules/components of the technology make it possible to transport on a normal size lorry; **preferred**.
- **Medium:** medium infrastructure demand. The size and the weight of the modules/components of the technology have a size and a weight that make it necessary to transport some of the components as special transport.
- **Poor:** high infrastructure demand. The size and the weight of the modules/components of the technology have a size and a weight that make it necessary to transport some of the components as special transport, and/or there is a need for reinforcement of the roads or construction of new roads.

## 9.1.7. P8: Technical installation time

The technical installation time is a critical parameter, as power capacity must be deployed rapidly to meet high winter demand.

This time frame encompasses all activities from preparing the building site to constructing the plant and commissioning the technology.

The qualitative assessment of this parameter is conducted on a three-level scale, based on the installation timeframe for the technology:

- **Good:** Installation can be completed in the short term, within less than 3 months; **preferred**.

- **Medium:** Installation requires a medium-term timeframe, ranging from 3 to 9 months.
- **Poor:** Installation is categorized as long-term, exceeding 9 months.

### 9.1.8. P9: Requirements for skilled staff in the construction and installation phase

The successful execution of energy projects depends on the availability of staff with the necessary skills and expertise. A skilled workforce, including experienced construction workers, engineers, project managers, environmental specialists, geologists, and safety professionals, is critical for the installation of many energy technologies. Due to the ongoing war, a significant shortage of skilled labour has emerged, making this parameter particularly essential. The workforce requirements vary across technologies. Modular technologies, for example, are relatively simple to set up and require fewer personnel compared to on-site construction projects, where the solution is built from the ground up and demands a larger, more skilled workforce.

This qualitative parameter is evaluated on a three-level scale, based on workforce requirements during the construction phase:

- **Good:** The construction phase requires fewer or less specialized personnel (low); **preferred**.
- **Medium:** The construction phase requires some skilled workforce (medium).
- **Poor:** The construction phase requires many and/or highly skilled and specialized personnel (high).

### 9.1.9. P10: Grid balancing capacity

Effective grid balancing is critical for the reliability of the supply of electricity. Therefore, this quality is assessed in the evaluation.

The stability of the grids is exposed to sudden system disruptions caused by attacks on transmission lines and power plants.

Grid balancing capacity refers to the ability of a power system to adjust and stabilize electricity frequency, voltage, and reactive power within acceptable ranges. Furthermore, it should be able to ensure that the supply of electricity matches the demand for electricity at any moment. The qualities such as performing black start-ups and providing inertia are also taken into account in the evaluations.

The qualitative parameter is addressed on a three-level scale, assessing the technologies abilities to balance the grid.

- **Good:** high ability to balance the system, e.g., battery systems; preferred.
- **Medium:** medium ability to balance the system, e.g., Thermal power plants (TPPs) with a high dynamic range, closed cycle gas turbine.
- **Poor:** low ability to provide the fundamental balancing services to the grid system like photovoltaics.

### 9.1.10. P11: Requirements for electricity grid infrastructure

The requirements for the grid infrastructure that are critical for enabling the technology to operate are evaluated. This parameter evaluates the level of critical requirements related to the technology's ability to operate.

The qualitative parameter is assessed on a three-level scale, which evaluates the technology's requirements for connecting to the electricity grid infrastructure.

- **Good:** Easy to connect, **preferred**.
- **Medium:** Moderate.
- **Poor:** Challenging.

## 9.1.11. P12: Requirements for skilled staff for operation and maintenance and special spare parts

In times of war, finding qualified personnel and specialized spare parts to operate and maintain energy production units can be challenging.

Specialized technicians and spare parts can be crucial for the ongoing maintenance of some energy systems. They conduct inspections, perform repairs, and ensure system reliability. The more specialized requirements for the O&M the higher the risk of forced outage and longer periods of no production.

This qualitative parameter is assessed on a three-level scale, assessing the requirements for skilled staff for operation and maintenance as:

- **Good:** Low specialization required for O&M, with minimal reliance on specialized staff and spare parts (low risk); **preferred**.
- **Medium:** Moderate specialization required for O&M, with some reliance on skilled staff and specific spare parts (medium risk).
- **Poor:** High specialization required for O&M, with significant reliance on highly skilled technicians and hard-to-source spare parts (high risk).

## 9.1.12. P13: Possibility for camouflage and sheltering

Evaluation of the properties of being able to camouflage and shelter is one way to assess how difficult it is to protect the technologies from attacks and how easy it is for the enemy to identify the location of the technologies. Therefore, these are important properties for the resilience of operation in Ukraine in the current situation. Technologies that have a high potential for camouflaging and sheltering are preferred.

The evaluation only clarifies how easy it is to protect the technology by camouflaging or sheltering, e.g., by covering it with a lid of concrete or protecting it with an anti-drone net[31]. Therefore, the assessment is based on the physical configuration[32] of the technology. Thus, there is no evaluation of what types of attacks the different shelters can withstand.

The rating of the parameter is given based solely on assessment of the surface area and the height above ground of the technology, seen in relation to attacks. For example, for wind turbines, it is difficult to protect them from drone attacks at 100 m height, while technologies that are at ground level (or maybe even can be

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31 Anti-drone nets are devices that are used to capture and disable drones that are flying in restricted or unwanted areas. They are usually launched from guns, bazookas, or other drones, and they have weights or hooks that can entangle the rotors of the target drone.

32 Physical configurations mean the surface area and the height above ground of the technology.

installed below ground level) could be easier to protect. Therefore, both the height and the surface area of the technologies and appurtenant components, e.g., fuel storage is considered. Thus, for example biomass and coal plants and biogas engines fuelled by gas from a biogas plant receives lower rating than, than gas turbines and gas engines fuelled by natural gas from the grid.

Chimneys are in this context similar to wind turbines, but they are less expensive to replace and less attractive to attack. Therefore, having a chimney does not necessarily mean a poor rating.

While the deployment of distributed energy generation units underground during wartime offers several advantages, it also presents challenges, including the cost of construction, maintenance, and the need for specialized expertise.

This qualitative parameter is assessed on a three-level scale, assessing the potential for camouflage and sheltering of a specific technology as:

- **Good:** easy to shelter or camouflage the most essential parts or a part, e.g., has a surface area that is insignificant and does not need to be uncovered or to be installed over surface level, and the need for discharge of exhaust gases is limited; **preferred**.
- **Medium:** possible to shelter or camouflage the most essential parts and do not have parts which have a surface area that is significant but is not put 100% out of service if only a small part of it is hit (e.g., biomass CHPs).
- **Poor:** not possible to shelter or camouflage the most essential parts (e.g. wind and PV) or a part that has a surface area that is significant and that is put out of service if only a small part of it is hit (e.g. biogas plants).

### 9.1.13. P14: Risk associated with fuel supply

An essential consideration is the risk related to fuel and potentially also spare parts supply because of the challenging supply situation. Hence, technologies that require minimal ongoing supplies after installation are preferred, such as renewable energy sources (wind, solar, water) that do not rely on fuel supply.

This parameter is assessed on a three-level scale, assessing the risks associated with the fuel and spare part supply:

- **Good:** low risk associated, defined as no need for fuel (e.g., hydro, PV, and wind); **preferred**.
- **Medium:** medium risk associated, defined as need for fuel that is locally produced (e.g., biomass and biogas).
- **Poor:** high risk associated, defined as the need for fuel that is not produced locally, e.g., natural gas, coal and oil or it is associated with a large infrastructure that can be seen as highly vulnerable.

### 9.1.14. P15: Restoration Time

Restoration time is critical in a war zone, where the ability to restore power quickly can reduce the duration of economic and social disruption. Modular systems that can be swiftly brought back online offer a significant advantage over larger, more centralized plants.

This new criterion emphasizes the ability to quickly restore power generation, with modular technologies offering significant advantages in minimizing downtime and restoring grid functionality.

Modular systems, such as small-scale renewables or quick-deploy gas turbines, have a comparative advantage due to their ability to be rapidly repaired or replaced after an attack.

This parameter is assessed on a three-level scale, evaluating the expected restoration time for each of the technologies on a three-level scale. The expectations are based on P6-Delivery time and availability of components and materials and P8-Technical installation time.

- **Good:** Restoration can be completed in the short term, within less than 2 months; **preferred**.
- **Medium:** Restoration requires a medium-term timeframe, ranging from 2 to 8 months.
- **Poor:** Restoration is categorized as long-term, exceeding 8 months.

10. Appendix B

# LCOE calculations

The calculation of the Levelized cost of electricity (LCOE) has been done by dividing the expenditure into the following categories, capital expenditure, operational expenditure, finance costs, fuel costs, and CO2 costs.

Every category supplies the expenditure per unit of nominal power. This expenditure has then been divided by the estimated production, which is going to be supplied by that unit of nominal power, to obtain the LCOE.

The capital expenditure per MW power was supplied by the Danish technology catalogue. Specifically for the battery, it is assumed that the battery should be able to deliver 1 MW for 4 hours, when the battery is fully charged.

The operational expenditure was derived by accounting for the fixed and variable operation and maintenance costs for the given technology's entire lifetime. The whole fixed O&M was derived by multiplying the annual fixed O&M with the technology's estimated lifetime. Both values were obtained from the Danish technology catalogue. The whole variable O&M was calculated by taking the cost per unit of power produced, which was supplied by the Danish technology catalogue and multiplying it with the estimated power production.

The estimated power production for wind turbines and photovoltaics is described in the chapters that describe how the PV and WPP production for each Ukrainian region is mapped. For plants that rely on fuels, the expected full load hours are 3 750 in the cold period and 5 000 during the whole year. The battery is expected to charge 4 hours during low consumption hours and discharge 4 hours during high consumption hours.

The fuel costs have been calculated by dividing the estimated power production with the name plate efficiency of each technology, which gives the fuel consumption, and then multiplying with the price of the fuel.

The nameplate efficiency of the technologies is provided in the data sheets, and the fuel prices stem from the Socioeconomic Calculation Assumptions provided by the Danish Energy Agency. Specifically for the battery plant, it is expected that the plant will charge with power produced from coal plants, as cheaper power plants will be used for baseload and the battery will not be expected to charge from peak load power sources. Therefore, the power price for the battery is expected to be the same as the marginal price for coal.

The $CO_2$eq emission costs have been calculated, by multiplication of the emission per MWh consumed fuel by fuel type, the fuel consumption, and the price per emission. The emission per MWh consumed fuel originates from the Socioeconomic Calculation Assumptions provided by the Danish Energy Agency and the cost of emitted $CO_2$eq is set as €80 per ton.

The finance cost is equivalent to what it would cost to finance the investment cost via a loan with an interest rate of 10% over 20 years or the full lifetime in case the full lifetime is shorter than 20 years.

# 11. Appendix C

# Cross cutting subjects

## 11.1. Positive list to speed up process grid connection for small power producing units and storage units

Implementation speed is one of the key parameters for a smooth transition to a more renewable-based energy system. A whitelist, named as a “positive list” in Denmark, is an innovative tool that simplifies the compliance validation process of connecting production, demand, and storage facilities to the electricity grid system.

A positive list contains pre-screened units with unit/equipment certificates (e.g., wind turbines, gas generators, non-synchronous hydro generators), and/or pre-screened plant components (e.g., certified PV inverters, power plant controllers, software applications) that meet the fundamental technical requirements according to the EU RfG Network Code (EU regulation 2016/631) and the EU DC Network Code (EU regulation 2016/1388). As the EU connection network codes are concerned about grid system stability, the requirements are organized in categories A, B, C, and D. The positive list is primarily interesting for developers/owners of small-scale units in categories A and B, but when applying many small-scale units in an aggregated manner to form a power plant, the positive list can also be interesting as compliance verification of the individual power module can be provided with an equipment certificate and shorten the compliance verification process. In addition, the relevant grid system operator only needs to inspect the equipment certificate once and thereby reduce time for the compliance verification process.

By using a positive list, grid system operators (TSO and DSO) and facility owners can save time and resources in the compliance approval process, while ensuring technical compatibility and securing grid stability.

The administrative responsibility of a positive list with time-limited pre-screened unit/equipment certificates and plant components is recommended to be hosted at the Ministerial level or eventually at the interest organization level, as implemented in Denmark. In Denmark, the concept of a whitelist (positive list) was created by the Danish TSO and later on, the responsibility for Positive lists was transferred to the DSOs’ interest organization, Green Power Denmark, as most of the benefits were harvested by the DSOs in Denmark.

The concept offers a streamlined approach for integrating small-scale energy storage units and generators into both the transmission and distribution grid system with the aim of simplifying the network compliance approval process for grid connections, benefiting both distribution system operators, project developers, and facility owners.

In addition to the whitelist (positive list), there is a need for approval and monitoring of the validity of applied equipment certificates/module certificates/unit certificates. The certificates typically have a time-limited validity (3-5 years).

The responsibility for approval and monitoring of certificate validity is located at the Ministry level in the department of the Danish Energy Agency named “Certification & Servicing (CAS)”. CAS is responsible for technical certification and servicing wind turbines. Only wind turbines with a unit certificate can be applied in Denmark.

The concept of positive lists and various certificates could be highly beneficial for countries looking to accelerate their renewable energy integration and grid modernization efforts. By adopting a similar system, other nations could:

1. Streamline Grid Connection Processes: Positive lists significantly reduce the administrative burden on distribution companies and facility owners. Instead of repetitive review of extensive technical documentation for a module/unit and numerous equipment certificates for each installation, developers can rely on pre-approved units, accelerating the compliance verification during the connection process.
2. Ensure Technical Compliance: The rigorous assessment process for inclusion on the positive list ensures that all listed units meet the necessary technical requirements. This standardization helps maintain grid stability and reliability as more distributed energy resources are connected.
3. Encourage Innovation: Manufacturers and suppliers are incentivized to develop products that meet or exceed the technical standards required for inclusion on the positive list. This can drive innovation in the energy storage, demand flexibility services, and generation sectors.
4. Enhance Transparency: A publicly available positive list provides clear guidance to facility owners, developers, and installers about which units are pre-approved for grid connection. This transparency can reduce uncertainty and streamline project planning.
5. Facilitate Market Entry: For countries aiming to develop their renewable energy markets, positive lists can lower barriers to entry for both domestic and international manufacturers, potentially leading to increased competition and reduced costs.
6. Improve Grid Flexibility: By simplifying the integration of small-scale storage and generation units, positive lists can contribute to a more flexible and resilient grid, better equipped to handle the variability of renewable energy sources.

To implement certification approval and monitoring and a whitelist (positive list) concept in a country could need to:

1. Establish a Governing Body: A Ministerial department, a sector interest organization like Green Power Denmark (DSO and power producers), an organization would need to be responsible for assessing and maintaining the various certificates and the whitelist (positive list).
2. EU regulation 2016/631 defines the minimum technical requirements: Clear, comprehensive technical standards for power producing modules, demand facilities and energy storage systems are already in place and are covering aspects such as minimum grid stabilizing services, robustness to grid disturbance, power quality, protection, electrical simulation models, compliance verification and safety.
3. Create compliance assessment Procedures: A standardized compliance verification process for evaluating units and inverters, including required documentation and testing protocols, would need to be established as required in the EU connection requirements.
4. A Submission System is in place: Authorized Certifiers responsible for issuing equipment/unit/module certificates exist where manufacturers and suppliers can submit their products for compliance assessment according to the EU regulations is already in place on EU as well as on the global market. The certifiers are authorized according to ISO/IEC 17065, 17025 and IECRE certification schemes.
5. Ensure Regular Updates: The positive lists would need to be regularly reviewed and updated to reflect technological advancements and changing grid requirements.

6. Educate Stakeholders: Distribution companies, facility owners, and manufacturers would need to be informed about the positive list system and its benefits.
7. Monitor Implementation: Ongoing evaluation of the system's effectiveness and impact on grid connections would be crucial for continuous improvement.

While the positive list system offers numerous advantages, it's important to note that it doesn't replace the need for site-specific assessments in all cases. As in Denmark, distribution companies should retain the right to request additional documentation when necessary, ensuring that local grid conditions and specific installation requirements are adequately addressed. By adopting a positive list system, countries can potentially accelerate their transition to cleaner energy sources, improve grid reliability, and reduce administrative burdens associated with the integration of small-scale energy resources. This approach could play a significant role in modernizing energy infrastructure and supporting the growth of distributed energy resources.

## 11.2. Grid stability related subjects

### 11.2.1. Operational challenges in the UA grid system

The current operational challenges in the UA grid system are characterized by frequent alerts or even emergencies in several areas. When a system operates in islanding mode, it is practicing being more robust against infrastructure disturbances. These disturbances could include:

- Missile/drone attack on grid substations, transmission, and distribution lines
- Dropout of large generation, storage, and demand facilities
- Lack of information exchange capability for short and midterm time windows in some areas
- Limited or temporary capability for control and monitoring of the grid system.

Recommended power generation technologies must have the capability to function in grid operational scenarios with intentional islanding, operating in a more distributed and autonomous manner adding a better dynamic stability to the individual grid islands. This is essential due to potential disruptions in communication and monitoring capabilities, including dropouts and extended periods of no data connection or data interrupting attacks from aggressive hackers.

Therefore, robust requirements for information security should be one of the highest priorities for new power generating systems, to secure the power supply even in isolated grid situations.

### 11.2.2. Challenges related to the integration of renewable energy technologies

To fully leverage the capabilities of variable renewable energy technologies, it is imperative that the operational strategies of the transmission system operator are specifically designed to manage the changes in the generation portfolio as well as the dynamics of the demand portfolio have changed over the years.

Taking into consideration the aforementioned information an interview was conducted with the transmission system operator "Ukrenergo", which offered valuable insights into their current operational practices. Based on the interview it appears that the current practices are not favourable for the implementation of renewable energy. The following will outline how.

The present operational planning and dispatching procedures lack the flexibility required to accommodate changes in the operation of variable renewable energy (VRE) sources. In order to ensure the optimal integration of VRE sources, such as wind power, solar power, battery/energy storage systems, and run-of-river hydropower, it is essential to operate the system with maximum flexibility, as close to the time of production as possible.

Adjustments of the balancing time window must be reconsidered for creating the room for more optimal VRE integration. While conventional generation portfolios typically operate with an operational planning window of several days or even a week, portfolios with a significant amount of VRE often operate with a planning window of less than an hour, sometimes as short as 5 or 15 minutes.

Additionally, the TSO's handling a very high level of VRE are dispatching/balancing the grid system using Balance Responsible Parties (BRPs) also named as aggregators for small scale power generating facilities as well as small scale demand facilities offering demand flexibility. Operating though BRPs are one of the main reasons for the very high security of supply level in Denmark with more than 65% of the total energy provide by VREs.

When addressing the necessity of flexibility, it is worth noting that a large amount of hydroelectric power plants (HPPs) with dams and pumped storage hydro (PHS) are already installed in Ukraine. HPPs and PHS are adding a large amount of flexibility to the UA energy system. HPPs and PHS are already used as storage systems for balancing and integrating variable renewable energy sources in parts of the Northen and Central European energy systems. However, it should be noted that nowadays water availability in the rivers in UA could become an issue.

Another issue brought up in the interview is the practice of curtailing solar. This suggests that an optimal dispatching based on least cost (economical dispatching) may not be currently applied.

The transition towards a more flexible power generating portfolio (more VRE) would require modernizing operational practices, e.g., to incorporate better forecasting of VRE to ensure an efficient economical operation of the energy technologies.

### 11.2.3. Standardized and secured information exchange

To cope with the current and near future situations with more and more intensive interruptions from cyber-attacks it is recommended to follow an international standardized digital approach (based on the ISO/IEC 27000 standard series and especially the ISO/IEC 27019:2024 – Information security, cybersecurity and privacy protection – Information security controls for the energy utility industry. The IEC 61850 standard series, the IEC 61400-25 (wind and solar) standard series, the IEC 62351 series) when retrofitting, extending, or repairing damaged data communication systems applied in the electricity sector. Based on the released EU Network Code for Cyber Security 2024/1366 of 11 March 2024 (NCCS) a series of coordinated activities on information exchange is recommended to be implemented as soon as possible.

The Network Code on Cybersecurity aims to set a European standard for the cybersecurity of cross-border electricity flows. It includes rules on cyber risk assessment, common minimum requirements, cybersecurity certification of products and services, monitoring, reporting, and crisis management. This Network Code provides a clear definition of the roles and responsibilities of the different stakeholders for each activity.

With the new Network Code in mind, robust requirements for information security should be one of the highest priorities for implementing new power generating systems, to secure supply in all system states and to support a strong cross-border exchange of power with UA and all European interconnected countries.

## 11.3. Risk of Gas Supply Cuts in Ukraine

According to the International Energy Agency (IEA), Ukraine's gas transmission system has been adapted to function without direct Russian imports since 2015. While Ukraine has maintained interconnections with Slovakia, Hungary, and Poland for potential imports, its domestic production and storage facilities have allowed it to achieve near self-sufficiency (IEA, 2024).

In 2024, Ukraine produced approximately 19.1 billion cubic meters (bcm) of natural gas, with a steady increase from 18.7 bcm in 2023. Meanwhile, domestic gas consumption has declined due to wartime economic contraction and efficiency measures, reaching around 19 bcm in 2024 (Reuters, 2024). This balance allowed Ukraine to meet its gas demand without imports during the 2023-2024 heating season (IEA, 2024). However, prolonged cold weather could significantly increase gas consumption, potentially straining reserves.

Throughout the war, Russia has so far refrained from targeting Ukraine's gas infrastructure to the same extent as its electricity infrastructure. The IEA notes that while Ukrainian power plants have been heavily attacked, gas infrastructure has remained largely intact (IEA, 2024). Most likely the gas transit agreement has provided Russia with an incentive to avoid damaging infrastructure used for European gas deliveries. However, with the agreement now abandoned, this constraint has disappeared; increasing the likelihood that Russia may begin targeting Ukraine's gas pipelines and storage facilities.

In fact, there are indications that since end of 2024, Russia has increasingly struck against Ukraine's gas infrastructure. For example, on February 1, 2025, a Russian air attack comprising six missiles and 17 Shahed drones targeted gas infrastructure and other facilities (Reuters, 2025).

Gas infrastructure, including pipelines, storage facilities, and processing plants, is vulnerable to air strikes, but the extent of the vulnerability depends on several factors, including the type of infrastructure, its design, and the nature of the attack. While underground pipelines and storages are less exposed, above-ground infrastructure, such as compressor stations and the surface infrastructure of underground storages (e.g., injection and extraction facilities) remain vulnerable to air attacks, which could disrupt distribution within Ukraine. This assessment is supported by the Ukrainian thinktank, Dixigroup, according to which "The main challenges for Ukraine's gas system remain military threats related to constant attacks on gas infrastructure and possible damage to above-ground facilities of underground gas storage facilities. Risks to production infrastructure are particularly dangerous."

### Sources


- International Energy Agency (IEA). (2024). "Ukraine's Energy Security and the Coming Winter." Retrieved from https://www.iea.org/reports/ukraines-energy-security-and-the-coming-winter
- Reuters (2025). "Russian air attack kills 15 in Ukraine, gas infrastructure targeted", https://www.reuters.com/world/europe/russian-air-attack-kills-three-ukraine-kyiv-says-2025-02-01/
- Dixigroup (2024). "WINTER OUTLOOK 2024/2025: GAS 19.11.2024". https://dixigroup.org/en/analytic/winter-supply-outlook-2024-2025-gas-2/


## 11.4. Financial issues

Under the current situation there could be some special requirements related to the financing. In the interviews some stakeholders mentioned that it can be difficult and expensive to get projects financed in UA because the accepted repayment period is low, and interest rates are high. Moreover, foreign investors such as IBRD (The International Bank for Reconstruction and Development and IFC (International Finance Cooperation) have stated that they are willing to invest during the war, however they will exclusively invest and provide loans to foreign companies because it is easier to insure any risks with foreign companies. Moreover, they expect support from the Ukrainian government in creating a so-called Master Plan or General Plan and in developing the projects, along with an Insurance Fund that would cover military risks. The government is working on the issue of military risk insurance. To that end, a Draft law “On the insurance of military risks” No 12372 dated 30 December 2024 was registered in Ukraine.

## 11.5. Transformers

Transformers are a critical component in the transmission and distribution of power. In the electrical supply the transformer changes the voltage of an alternating current. In power generation plants, such as gas turbines, diesel generators and wind turbines, the change of the voltage is essential to obtain the same voltage as that of the grid, to which the plants are connected. The voltage levels of the grid depend on specific designs, but typically the longer power is transmitted, the higher the voltage levels.

Furthermore, transformers are also used to step down the power levels, to stages until the power level matches the power level of the consumer.

Because transformers are needed to couple the plants with a specific electrical grid, transformers can become a limiting factor for the different power producing technologies.

Transformers come in many complexities and capacities. They can be supplied in modular forms or be tailor made to the given plant. The general categories are provided below.

*Table 43 : Transformers categories and their key parameters*

| Category | Apparent power rating | Weight | Description |
|---|---|---|---|
| Small transformers | <500 kVA | 1kg-2 tons | Transformers used in residential neighbourhoods |
| Medium transformers – Distribution grids | 500 kVA-10 MVA | 1-15 tons | Transformers used in substations – Step down |
| Medium transformers – Plants | 1 MVA-50 MVA | 5-100 tons | Used for smaller plants – Step up |
| Large transformers | >50 MVA | 70-400 tons | Used for major substations and power generation plants – Step up |

The weight, shape and size can limit the use case for different transformers in Ukraine. Some cannot be transported across bridges due to their weight, and some might have the wrong size to transport.

The weight and shape and size depends on whether the transformer is dry type or oil immersed, the oil immersed is anticipated to be most relevant in this context.

The delivery time of a transformer might pose a hinderance to the completion of a project, even though gas turbines, diesel generators, wind turbines etc. are available, it might not be plausible to couple them to the grid, therefore the delivery time of the transformers needs to be taken into consideration. The delivery time of large transformers is estimated to be around 1-2 years whereas small transformers may be supplied within a couple of weeks.

*Table 44: Estimated delivery time per transformer category*

| Category | Time estimates for delivery |
|---|---|
| Small transformers | 2 weeks |
| Medium transformers – Distribution grids | 40 weeks |
| Medium transformers – Plants | 20-28 weeks |
| Large transformers | 1-2 years |

12. Appendix D

# Methodology for determining PV resource potentials in Ukraine

## Calculation methods and assumptions for the charts

This section refers to the Figure 12 that shows the expected annual PV generation (MWh per MW installed capacity) in different regions of Ukraine. The maps are set up calculating the generalized power generation from photovoltaics in the different Ukrainian regions, a raster map covering all of Ukraine from Global Solar Atlas was used. The raster map of Ukraine contains the yearly average potential production [kWh/kWp], covering the period between 1994 and 2018, given in a pixel containing the average value. Each raster pixel is given in a resolution corresponding to a measurement per approximately 650 m. The potential production average is based on the average theoretical production, which is based on solar irradiance measured by geostationary satellites and the theoretical power production of a free-standing photovoltaic power plant, with stationary modules mounted at the optimal tilt in order for the modules to obtain a monthly maximum power production at the specific site.

Through Quantum Geographic Information System (QGIS), the values of the raster layer have been aggregated as an average for each Ukrainian region, so that the annual potential production average of photovoltaics [kWh/kWp] is given for each Ukrainian region.

This section refers to Figure 11 that shows the expected wintertime PV generation (MWh per MW installed capacity) in different regions of Ukraine. To calculate the average potential production of photovoltaics in the winter period, October to March, multiple raster maps from Global Solar Atlas were used. These raster maps contained the daily potential production average from 1994-2018 for each of the corresponding months. Meaning that the daily values were an average aggregate of the days in the corresponding month. Therefore, the daily values for each month were calculated for each Ukrainian region and the average daily values for each Ukrainian region were multiplied by the number of days in the corresponding month and summarized with the potential production of the other months in the cold period, where the monthly values were obtained in the same manner.

This calculation was also done for all of Ukraine, and the average power production of the photovoltaics in all of Ukraine, on an annual basis and during the cold period, was used as the estimated power consumption in the LCOE calculation.

As large photovoltaic power plants might be easily targeted by artillery and close-range ballistic missiles (CRBM), a buffer zone of 100 km and 280 km was applied from Russian controlled areas and Belarus, accounting for the longest range of Russian artillery and CRBMs. These two means of attack are considered, as the projectiles might be harder to intercept for the Ukrainian missile defence system.

13. Appendix E

# Methodology for determining wind resource potentials in Ukraine

To calculate the generalized power generation from wind turbines, in different Ukrainian regions, a raster map covering all of Ukraine was used. The raster map originated from Global Wind Atlas. The raster map contains the yearly capacity factor of wind turbines in the class IEC2[33]. This capacity factor has been derived through the calculation of power curves of IEC2 classes in relation to wind speeds that have been modelled through GWA version 3, which uses ERA5 datasets that have been supplied by the European Centre for Medium-Range Weather Forecasts. The ERA5 datasets are obtained through satellite measurements, which have been validated by radar measurements. The capacity factor is based on the average aggregate of the wind speeds between the year 2008 and 2017. The capacity factor is given as a pixel containing a value that has a resolution corresponding to the approximate distance of 200-250 meters between each measurement.

Through QGIS, the values of the raster layer have been aggregated as an average for each Ukrainian region, so that the annual capacity factor of the turbines in class IEC2 have been given for each Ukrainian region. Through the capacity factor, the full load hours of the wind turbines were calculated, by using the wind turbine provided in the technology catalogue as a reference. The generating capacity for that wind turbine is 4.2 MW with a hub height of 85 m and rotor diameter of 130 m. The raster map, containing the capacity factor of IEC2 class turbines, was used, as the wind turbine in the technology catalogue is an IEC2 class turbine, which means the wind profiles fit.

In order to calculate the full load hours of wind turbines in each Ukrainian region during the cold period, October to March, an hourly wind profile for 2019 from Renewables Ninja was assessed. It was concluded that 51% of the full load hours occurred during the cold period. This percentage was then used to calculate the full load hours for each region in Ukraine, during the cold period, by time multiplication for each region.

This calculation was also done for all of Ukraine, and the average power production of the wind turbines in all of Ukraine, on an annual basis and during the cold period, was used as the estimated power consumption in the LCOE calculation.

As wind turbines might be easily targeted by artillery and CRBMs, a buffer zone of 100 km and 280 km was applied from Russian controlled areas and Belarus, accounting for the longest range of Russian artillery and CRBMs. These two means of attack are considered, as the projectiles might be harder to intercept for the Ukrainian missile defence system.

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33 IEC Class 1 turbines are generally for wind speeds greater than 8 m/s. These turbines are tested for higher extreme wind speed and more severe turbulence. IEC Class 2 turbines are designed for average wind speeds of 7.5 m/s to 8.5 m/s. IEC Class 3 turbines are designed for winds less than 7.5 m/s. These turbines will need a larger rotor to capture the same amount of energy as a similar turbine at a Class II site. Source.

14. Appendix F

# Data sheets (separate file)

# 15. Appendix G

# Review of Resilience Criteria

In the edition 1 (January 2024) of the Urgent Technology Catalog for Ukraine (UTC 2024), the resilience of electricity generation technologies is evaluated based on five key parameters:

- **Distributed Generation** – 30% weight
- **Possibility for Camouflage and Sheltering** – 30% weight
- **Grid Balancing Capacity** – 15% weight
- **Risk Associated with Fuel Supply** – 15% weight
- **Requirements for Skilled Staff and Special Spare Parts** – 10% weight

Each technology is assessed relative to the performance of other technologies across these five criteria, with each parameter weighted according to its importance.

This note seeks to review, enhance, and systematize the resilience criteria for energy infrastructure technologies. The review comes against a grim backdrop: in the autumn of 2024, Russia continued its large-scale attacks on Ukraine's energy infrastructure. Public reports indicate that approximately **60% of Ukraine's electric power generation capacity** has been destroyed. Recently, Russia has begun targeting infrastructure surrounding Ukraine's remaining nuclear power plants to prevent them from feeding power into the grid[34].

The review process involves the following steps:

- Assessing Threats to the Ukrainian Energy Sector
- Exploring Mitigation Measures
- Analyzing Costs Related to Attacks on Energy Infrastructure
- Reviewing TSO/DSO Approaches to Resilience Assessment
- Evaluating Resilience Assessment Criteria with Suggested Changes
- Proposing a Revised Evaluation Methodology for Resilience Assessment

This approach will help refine and adjust resilience measures for energy infrastructure, taking into account the evolving threats and need for system robustness in Ukraine's current context.

## Threats to the Ukrainian energy sector

34 "Russia, Targeting Ukraine's Grid, Moves to Cut Off Its Nuclear Plants", New York Times, 29. Nov 2024, "Ukraine strengthens its energy infrastructure as Russian attacks intensify", El Pais, 5 Dec 2024

Ukraine's energy infrastructure faces significant threats due to its critical role in sustaining the country's economy and its resilience during conflict. The threats can be categorized as follows:

**Aerial strikes,** including missile and drone attacks, have repeatedly targeted Ukraine's energy infrastructure. According to reports, Russia has conducted extensive bombing campaigns against power plants, substations, and the national grid, particularly during the winter months to undermine civilian morale and economic stability. High-precision missiles and Iranian-made drones (Shahed-136) have been used to disable critical facilities, resulting in widespread power outages and disruptions to heating and water supplies.

These attacks have a direct and immediate impact, creating long repair times and exposing vulnerabilities in interconnected systems. Public sources and analysts agree that aerial strikes are one of the most devastating forms of attack against Ukraine's energy systems due to their scale, frequency, and effectiveness.

**Sabotage** poses a more covert threat to energy infrastructure. Sabotage operations may involve physical damage to power lines, substations, or gas pipelines, often carried out by infiltrators or special operations units. Such incidents can be difficult to prevent, as they exploit gaps in physical security. Reliable information about the extent and effectiveness of sabotage in Ukraine remains limited, however sabotage operations are considered much less frequent than aerial strikes.

Ukraine's energy infrastructure has been a long-standing target of **cyberattacks**, with notable incidents such as the 2015 and 2016 attacks on its power grid[35]. These attacks, attributed to Russian groups like Sandworm, demonstrated the ability to cause blackouts by targeting control systems and disabling power stations remotely.

Based on public reports and analyzes, **aerial attacks pose the greatest threat** to Ukraine's energy infrastructure. These attacks are consistent, impactful, and strategically aimed at crippling critical facilities during key moments of the conflict. While sabotage and cyberattacks also pose significant risks, they are secondary in scale and immediate impact compared to the sustained and highly destructive aerial campaigns.

## Mitigation measures

Measures or strategies aimed at avoiding threats to Ukraine's critical infrastructure and civilian safety could be broadly categorized as **risk mitigation strategies** or **resilience measures**. These strategies are designed to reduce the impact of various threats and ensure the continued functioning of essential systems under stress.

It is relevant to distinguish between the following types of measures or strategies:

1. **Preventive Measures:** Actions taken to minimize the likelihood of threats, such as implementing robust cybersecurity protocols.
2. **Protective Measures:** Strategies to shield key infrastructure, including deploying air defense systems, hardening substations, converting overhead lines to cables, or using encryption to safeguard communication networks.
3. **Resilience Planning:** Developing contingency plans, redundancy systems, and rapid recovery strategies to maintain functionality or restore services quickly after an incident.
4. **Countermeasures:** Active strategies to neutralize threats, such as intercepting aerial threats or countering cyberattacks in real time.

It is our understanding that Ukraine employs a comprehensive strategy to address the threats posed by aerial attacks, sabotage, and cyberattacks, leveraging all four key approaches.

35 https://www.wired.com/2016/03/inside-cunning-unprecedented-hack-ukraines-power-grid/

## Costs related to the attack on energy infrastructure

Russia's systematic attacks on Ukraine's energy infrastructure can be seen as a deliberate cost-benefit strategy, where the goal is to maximize damage to Ukraine's economy and society using limited resources like missiles and drones. This strategy has multiple layers of impact:

1. **Physical destruction:** The direct loss of infrastructure, such as power plants and grid components, represents a tangible and immediate economic setback, reducing Ukraine's capacity to deliver electricity to its population and industries.
2. **Economic loss from unserved energy:** Interruptions to electricity supplies create cascading economic and societal costs, including lost industrial productivity and severe impacts on households. While challenging to quantify, prolonged outages of critical infrastructure could result in the most significant financial losses over time.
3. **Forced investments in mitigation:** Ukraine is compelled to invest heavily in defensive measures like air defense systems and grid resilience, as well as in countermeasures and rebuilding, diverting resources from other vital areas.

The high cost of unserved energy and the difficulty of restoring large conventional power plants make resilience planning vital for Ukraine's energy sector. In this context, modular and distributed energy solutions—such as wind turbines, solar power plants and small gas turbines, as well as energy storage systems (batteries and smart software) offer distinct advantages:

- **Faster Replacement:** Modular units can be replaced more quickly than bespoke equipment typically used in conventional power plants, where rebuilding requires specialized components and extended timelines.
- **Redundancy and Flexibility:** Distributed systems are inherently more resilient. For example, a wind farm continues to operate even if individual turbines are damaged, and solar plants remain functional even if parts of the installation are destroyed.

By contrast, conventional power plants, which rely on large-scale, centralized systems, may face longer recovery times due to their reliance on unique and complex components. New large-scale conventional power plants require simultaneously to attract huge funds from one or few sources, while modular systems are also distributed in terms of sources of financial resources. These factors underscore the potential benefits of integrating modular, renewable energy solutions into Ukraine's energy strategy to enhance resilience and ensure continued power supply in the face of ongoing threats.

## Example of cost related to the attack on energy infrastructure

### Destruction of a 300 MW coal Power Plant

The replacement cost of a 300 MW thermal power plant:

- Replacement cost: At €2 million per MW, the total comes to €600 million.

### Energy Not Served from the same 300 MW Power Plant

The economic cost of energy not supplied due to the destruction of this plant can be immense, depending on the duration of the outage:

- 1 Month: Assuming 50% of the potential power generation cannot be supplied by other sources and a Value of Loss Load (VOLL) of €10 000/MWh[36] (0.01million €/MWh), the cost is calculated as:
- 50%*300MW*24hours/day*30.5days/month*0.01million €/MWh = €1 100 million.
- 6 Months: Using the same assumptions, the cost escalates to €6 600 million.
- 2 Years: The total cost rises to €26 400 million if replacement generation is not provided.
- Note, the value of lost load (VOLL) depends on the region/economic, economic activity, and the sector being analyzed (see footnote)

### Active Defense Measures

To protect energy infrastructure, advanced defense systems like C-RAM (Counter-Rocket, Artillery, and mortar) systems can be deployed. C-RAM is a point-defense weapon system designed to intercept and destroy incoming threats such as drones, rockets, artillery shells, and mortar rounds.

- Coverage: A single C-RAM system defends approximately 1.3 km$^2$.
- Cost: Each system costs approximately €3.6 million.
- Effectiveness:
  - High effectiveness against slow-moving threats such as drones, rockets, and mortar rounds.
  - Limited effectiveness against high-speed or swarming threats like ballistic and cruise missiles.

## Preliminary findings regarding costs related to the attack on energy infrastructure

The potentially largest costs from attacks on energy infrastructure are related to energy not served, as shown by the example of a 300 MW power plant. This highlights the critical need for energy systems designed with inherent redundancy and modularity. Modular facilities allow damaged components to be quickly replaced, significantly reducing downtime and mitigating economic losses.

[36] The Value of Lost Load (VoLL) quantifies the economic cost associated with unserved electricity, typically expressed in euros per megawatt-hour (€/MWh). Estimates of VoLL vary significantly across regions and sectors, influenced by factors such as economic activity, consumer type, and reliability of supply. Examples of VoLL Estimates: European Union: VoLL values range from approximately €1 500 to €23 000 per MWh, varying by country and consumer segment (Swin and GP et al. 2019: The Value of Lost Load (VoLL) in European Electricity Markets: Uses, Methodologies, Future Directions). Great Britain: Research commissioned by Ofgem estimated VoLL for domestic consumers at around £17 000 per MWh, with variations observed across different consumer groups (London Economics 2013, The Value of Lost Load (VoLL) for Electricity in Great Britain). Factors Influencing VoLL: Consumer Type: Industrial and commercial consumers often have higher VoLL due to the substantial economic losses incurred during outages, compared to residential consumers. Duration and Timing of Outage: Longer outages and those occurring during peak business hours generally result in higher VoLL, reflecting increased disruption costs. Economic Structure: Regions with economies heavily reliant on continuous processes or high-value services may exhibit higher VoLL. Seasonal and Climatic Factors: In areas with extreme weather conditions, power outages can have more severe consequences, influencing VoLL. Considering Ukraine's current economic structure, energy consumption patterns, and the critical importance of electricity supply, a VoLL estimate of €10 000 per MWh is deemed appropriate for assessing the economic impact of power outages in the country.

While air defense systems like C-RAM are relatively inexpensive compared to the damage they aim to prevent, their availability remains limited, making them a scarce resource. This limitation emphasizes the importance of strategic allocation and the need for innovative solutions to counter increasingly sophisticated threats, such as swarming drones and high-speed missiles.

Large power plants face additional vulnerabilities. Beyond protecting the plant itself, nearby substations that transmit power to the grid and consumers, fuel storages and fuel transport infrastructure also require defense. This adds complexity to security efforts and underscores the benefits of a decentralized supply structure, which disperses generation capacity to limit the impact of targeted attacks.

These observations strengthen the case for an energy strategy centered on distributed and modular facilities. Such a strategy not only reduces vulnerabilities but also enhances resilience through:

- Limiting the impact of individual strikes by spreading generation capacity.
- Enabling faster recovery through modular designs.
- Avoiding the need to defend large, complex, and interdependent systems.

## TSO/DSO approaches to assessing resilience

Typically, Transmission System Operators (TSOs) and Distribution System Operators (DSOs) are responsible for ensuring power supply security. They coordinate with power producers to maintain a stable power grid through market mechanisms and transmission controls. To ensure grid reliability, TSOs, DSOs, and power suppliers implement auxiliary systems, which are redundancies designed to keep the grid operational during contingencies, such as storms or routine maintenance. The cost-effectiveness of these redundancies is assessed using probabilistic risk analysis, particularly for non-military events.

Probabilistic risk assessments typically involve constructing a matrix that evaluates the likelihood of an event occurring against the severity of its consequences, as shown in Table 45.

*Table 45: Provides a visual example of how a probabilistic risk assessment can be conducted and visualized. Where the green, yellow, and red fields, as well as their values, should be viewed as events.*

| Likelihood | Consequences | | | | |
|---|---|---|---|---|---|
| | Insignificant | Minor | Moderate | Major | Catastrophic |
| Certain >90% chance | High | High | Extreme | Extreme | Extreme |
| Likely >50% - 90% chance | Moderate | High | High | Extreme | Extreme |
| Moderate >10% - 50% chance | Low | Moderate | High | Extreme | Extreme |
| Unlikely >3% - 10% chance | Low | Low | Moderate | High | Extreme |
| Rare <3% chance | Low | Low | Moderate | High | High |

In practice, predicting the likelihood of these events is difficult and varies by location. Operators collect and analyze data from various parts of the grid and power plants to refine risk assessments and improve mitigation strategies. This allows for better-targeted redundancies and cost reductions. These analyzes are often done at the component level, for example, assessing the risk of a bolt failure in a transmission line and its impact on power supply.

The TSO/DSO approach to assessing resilience offers a methodical framework for addressing power supply disruptions, relying on probabilistic risk analysis and targeted redundancies to mitigate non-military risks such as natural disasters or technical failures. While this is a sound approach for relatively stable environments, applying it in the Ukrainian context presents significant challenges due to the acute and severe threats posed by ongoing military attacks.

Unlike the typical contingencies considered by European TSOs/DSOs (e.g., storms, equipment failure), Ukraine faces regular and intentional destruction of energy infrastructure, including missile strikes and drone attacks. The frequency and intensity of these events far exceed the scenarios modeled in probabilistic risk for non-military threats.

The intentional targeting of critical infrastructure in Ukraine creates dynamic risks that are difficult to quantify and mitigate using standard probabilistic matrices. These analyzes rely heavily on historical data, which may not apply to the volatile wartime conditions Ukraine experiences.

While assessing risks at the component level (e.g., a bolt failure) helps optimize maintenance in stable contexts, Ukraine's situation requires system-wide resilience strategies. For example, addressing vulnerabilities in interconnected substations or ensuring distributed redundancy across the grid is more critical than focusing on individual components.

In conclusion, the TSO/DSO resilience approach offers a foundational methodology, but Ukraine's context demands adaptations to address its unique challenges.

## Evaluation of criteria for resilience assessment with suggested changes

1. **Distributed Generation (UTC 2024: 30% weight, UTC 2025: 25% weight):**
    - **Evaluation:** Distributed generation (DG) is increasingly recognized as a critical resilience feature in energy infrastructure. Ukraine's experience with power plant attacks has demonstrated that **distributed technologies** — such as small-scale, modular systems are less vulnerable to large-scale attacks. These systems can be more easily replaced or restored, and local generation reduces dependence on centralized infrastructure that could be a target for strikes. Real-world experiences from Ukraine and other conflict zones highlight that distributed generation increases grid resilience.
    - **Suggested Adjustment:** Given the growing recognition of the advantages of DG in high-risk environments, it should be maintained as a key criterion. The resilience of such systems to targeted strikes enhances energy security by diversifying risk. The weight of this criterion is adjusted to 25%.
2. **Possibility for Camouflage and Sheltering (UTC 2024: 30% weight, UTC 2025: 15% weight):**
    - **Evaluation:** While **sheltering and camouflage** are important, Ukraine's experience has shown that **drone swarms and missiles** can overwhelm traditional protection strategies. Additionally, protecting infrastructure from these types of advanced attacks is extremely complex and costly. Effective camouflage may offer some protection, but it is often insufficient against the range of modern threats.
    - **Suggested Adjustment: Lower the weigh**t of this criterion to around **15%**, to better reflect its diminishing effectiveness against sophisticated aerial threats. Focus could shift more towards the ability to quickly restore and replace damaged infrastructure.

3. **Grid balancing Capacity (UTC 2024: 10% weight, UTC 2025: 10% weight):**
   - **Evaluation: Grid balancing** remains highly relevant, especially with increased integration of renewable energy and intermittent sources like solar and wind. The ability to flexibly adjust generation is crucial for maintaining grid stability during demand peaks or outages. Flexible units, such as gas turbines or battery storage, can provide power when needed most, helping stabilize the grid.
   - **Suggested Adjustment: Lower the weight of this criterion to 10%**, while the value of flexible units remains significant, particularly in areas where grid stability is essential. The ability to deliver power during disruptions or high-demand periods enhances resilience.
4. **Risk associated with Fuel Supply (UTC 2024: 15% weight, UTC 2025: 30% weight):**
   - **Evaluation:** Ukraine's decision to **not reaffirm its gas transit contract with Gazprom** poses challenges for sourcing fuel, especially natural gas. This could make **gas infrastructure** more vulnerable to targeted attacks by Russian forces. Furthermore, the potential difficulty in sourcing fuel under a blockade[37] scenario increases the risk of interruptions to power generation.
   - **Suggested Adjustment: Increase the weight** to 30% for this criterion to reflect the higher importance of fuel security in Ukraine's, in particular the potential threats to the gas infrastructure.
5. **Requirements for Skilled Staff and Special Spare Parts (UTC 2024: 10% weight, UTC 2025: 10% weight):**
   - **Evaluation:** The requirement for **skilled staff** and **special spare parts** remains important for long-term maintenance and operational continuity. Shortages of skilled staff have been mentioned as a key concern by stakeholders. However, the **immediate threats** faced by Ukraine (e.g., aerial attacks) may overshadow the longer-term concerns about staff availability in a crisis. In the short term, the priority is often restoring functionality rather than maintaining routine operations.
   - **Suggested Adjustment: Retain the weight of** this criterion at 10%.
6. **Restoration (New Criterion, UTC 2025: 10% weight):**
   - **Suggested Addition:** A new criterion should be introduced to evaluate the **restoration time** for electricity generation technologies. Modular systems, such as small-scale renewables or quick-deploy gas turbines, have a comparative advantage due to their ability to be rapidly repaired or replaced after an attack. On the other hand, equipment (e.g., turbines, transformers, switchgear) for larger thermal generators is often custom-built and many Ukraine's plants use Soviet-era equipment, requiring adaptation or custom engineering for replacements.
   - **Evaluation: Restoration time** is critical in a conflict zone, where the ability to restore power quickly can reduce the duration of economic and social disruption. Modular systems that can be swiftly brought back online offer a significant advantage over larger, more centralized plants.
   - **Suggested Weight: 10%**. Restoration time directly impacts the recovery and resilience of the power grid during ongoing threats and crises.

[37] E.g., for coal, the major domestic supply was from the now Russian-occupied Donbas region, and the import was mainly from Russia before the war. Therefore, it has been necessary to establish other sources for coal supply (e.g., Australia), which has made sourcing more difficult.

## Revised evaluation methodology for resilience assessment

Given the specific challenges faced by Ukraine in terms of energy infrastructure resilience, a revised methodology has been proposed to more effectively evaluate electricity generation technologies. This methodology considers the importance of distributed, modular solutions and the ability to quickly restore power after attacks, while adjusting for the unique risks Ukraine faces. The revised evaluation methodology is as follows[38]:

1. **Distributed Generation (25%):** Recognizing the advantages of decentralized energy systems, which are less vulnerable to large-scale attacks and can be quickly restored, this criterion remains the most heavily weighted.
2. **Possibility for Camouflage and Sheltering (15%):** While still important for protection against aerial threats, the effectiveness of camouflage is limited against sophisticated drone swarms and missile attacks, reducing the weight of this factor.
3. **Grid Balancing Capacity (10%):** The ability to balance grid demand, especially with renewable energy integration and storages (home- and industrial batteries), remains crucial for maintaining grid stability, making this factor still highly relevant.
4. **Risk Associated with Fuel Supply (30%):** With Ukraine's evolving fuel security situation, particularly related to gas supply and infrastructure vulnerability, this factor becomes increasingly critical and requires a higher weight.
5. **Requirements for Skilled Staff and Special Spare Parts (10%):** While important for long-term operational continuity, the need for skilled staff and specialized parts is secondary in the face of immediate threats and the focus on rapid recovery.
6. **Restoration Time (10%):** This new criterion emphasizes the ability to quickly restore power generation, with modular technologies offering significant advantages in minimizing downtime and restoring grid functionality.

[38] The weightings have been changed due to the highlight of the shortage of staff in the interviews.

# 16. Appendix H

# Accelerating Renewable Energy Deployment in Ukraine alignment with EU requirements: The Role of Article 15b and Renewables Acceleration Areas (RAAs)

## Introduction

The European Union (EU) is committed to achieving ambitious renewable energy and climate goals as part of its Green Deal and broader decarbonization objectives. A key instrument to accelerate this transition is the revised Renewable Energy Directive (RED), particularly Articles 15b and 15c, which focus on identifying and designating areas suitable for renewable energy development and establishing Renewables Acceleration Areas (RAAs). These provisions aim to streamline permitting processes and address bottlenecks that hinder renewable energy deployment.

This note provides an overview of the requirements outlined in Articles 15b and 15c, criteria for selecting suitable areas for renewable energy projects, and their implications for Member States. Additionally, it considers Ukraine's alignment with these policies as part of its integration with the EU energy framework.

### Article 15b: Identification of Suitable Areas

Article 15b requires EU Member States to identify areas suitable for renewable energy projects, forming the foundation for the establishment of RAAs under Article 15c. The primary objective is to designate zones where renewable energy deployment is both environmentally and economically viable while minimizing conflicts with other land uses. These areas are pre-assessed to ensure that projects can proceed with reduced permitting and administrative obstacles.

### Deadlines Under Article 15b

- **21 May 2025:** Member States must identify and adopt one or more plans designating suitable areas for renewable energy projects in line with Article 15b requirements.

**Criteria for Identifying Suitable Areas**

To meet the objectives of Article 15b, Member States must apply specific criteria to determine which areas are most appropriate for renewable energy development. These criteria fall into several broad categories:

1. **Environmental Criteria**
   - Avoidance of protected areas under EU environmental laws, such as Natura 2000 sites, national parks, and areas hosting critical biodiversity.
   - Consideration of environmental sensitivity through tools like Strategic Environmental Assessments (SEA) and Environmental Impact Assessments (EIA).
   - Avoiding regions with high ecosystem fragmentation risks or habitats for endangered species, while promoting projects on degraded or low-value land.
2. **Land-Use and Spatial Criteria**
   - Prioritization of degraded land, industrial zones, and brownfields over greenfield development.
   - Integration with national spatial planning policies, ensuring that renewable energy development aligns with broader land-use objectives.
   - Avoidance of high-value agricultural land to protect food security and minimize land-use conflicts.
3. **Technical and Resource Potential**
   - Identification of areas with high renewable energy potential, such as strong wind speeds, high solar irradiation, or geothermal capacity.
   - Proximity to existing grid infrastructure to facilitate efficient grid connections and minimize costs.
   - Accessibility for construction and maintenance, leveraging existing transportation infrastructure where possible.
4. **Social and Economic Considerations**
   - Avoiding areas with strong community opposition while ensuring benefits for local populations through jobs, revenue-sharing, or improved energy access.
   - Respecting cultural and historical heritage sites to minimize social resistance.
5. **Climate Resilience**
   - Selecting areas that are less vulnerable to climate-related risks, such as extreme weather events or rising sea levels, ensuring that renewable energy infrastructure remains resilient.

The Directive encourages Member States to develop a **transparent and participatory process** for identifying areas under Article 15b, involving:

- Stakeholders such as local authorities, community groups, and environmental organizations.
- Use of Geographic Information Systems (GIS) and mapping tools to analyze technical, environmental, and social constraints.

**Article 15c: Renewables Acceleration Areas (RAAs)**

Building on the framework established by Article 15b, Article 15c requires Member States to designate specific zones within the identified suitable areas as Renewables Acceleration Areas (RAAs). These zones benefit from streamlined permitting and administrative processes designed to fast-track renewable energy deployment.

#### Deadlines Under Article 15c

- **21 February 2026:** Member States must formally adopt plans designating RAAs within the suitable areas identified under Article 15b.

#### Features of RAAs

- **Simplified Permitting Processes:** Permits for renewable energy projects in RAAs are subject to faster processing times, often capped at one year for standard projects.
- **Pre-Assessment:** Environmental and planning constraints are addressed during the RAA designation process, reducing the likelihood of delays or conflicts during project implementation.
- **Predictability for Developers:** Developers working within RAAs can expect greater clarity and reduced risks, incentivizing investment and accelerating project timelines.

### Connection to Other Provisions in RED

Articles 15b and 15c are part of a broader framework within the RED to address barriers to renewable energy deployment. These include:

1. **Article 15a: Enabling Conditions** Article 15a establishes broader conditions for reducing administrative barriers, including digital permitting, centralized contact points for developers, and time limits on permitting decisions. RAAs operationalize these principles within specific geographic zones.
2. **Article 16: Simplified Permitting for Specific Projects** Article 16 outlines specific timelines and procedures for permitting renewable energy projects, particularly repowering, solar installations, and grid upgrades. RAAs benefit from these provisions, with an even greater focus on simplification and predictability.
3. **Article 3: Renewable Energy Targets** Article 3 sets binding national contributions to the EU's 2030 renewable energy target. RAAs are instrumental in helping Member States meet these obligations by facilitating the rapid deployment of renewable energy capacity.

### Examples of Implementation in EU Member States

Several EU Member States are taking steps to implement Articles 15b and 15c, although the process is ongoing:

- **Spain:** Spain has begun mapping suitable areas for renewable energy projects, prioritizing regions with high solar and wind potential. Existing zoning frameworks are being adapted to align with the RED requirements.
- **Germany:** Germany is advancing spatial planning initiatives to identify areas for renewables, focusing on integrating these zones with its national energy transition strategy (Energiewende). However, delays in transposing the directive highlight challenges in meeting EU deadlines.
- **France:** France has developed regional energy plans that align with the principles of Articles 15b and 15c, identifying zones for solar and offshore wind development.

### Ukraine's Alignment with EU Policies

Although Ukraine is not an EU Member State, it is aligning its energy policies with EU standards as part of its commitment to the Energy Community Treaty. This alignment includes:

1. **Legislative Framework:** Ukraine has adopted renewable energy targets and permitting reforms consistent with the EU RED.

2. **Spatial Planning:** Ukraine is working to identify suitable areas for renewable energy development, focusing on solar and wind projects in the south and southeast.
3. **Post-War Reconstruction:** Renewables are central to Ukraine's reconstruction efforts, supported by EU funding and technical assistance.

While Ukraine is not obligated to establish RAAs, its efforts to streamline permitting and prioritize renewables reflect the principles of Articles 15b and 15c. These actions position Ukraine as a potential future adopter of the directive should it join the EU.

17. Appendix I

# Local Ukrainian biomass – potential, collection, and treatment processes (separate file)