Danish Energy Agency

Ministry of Energy of Ukraine

Urgent Technology Catalogue

For the Ukrainian Power Sector

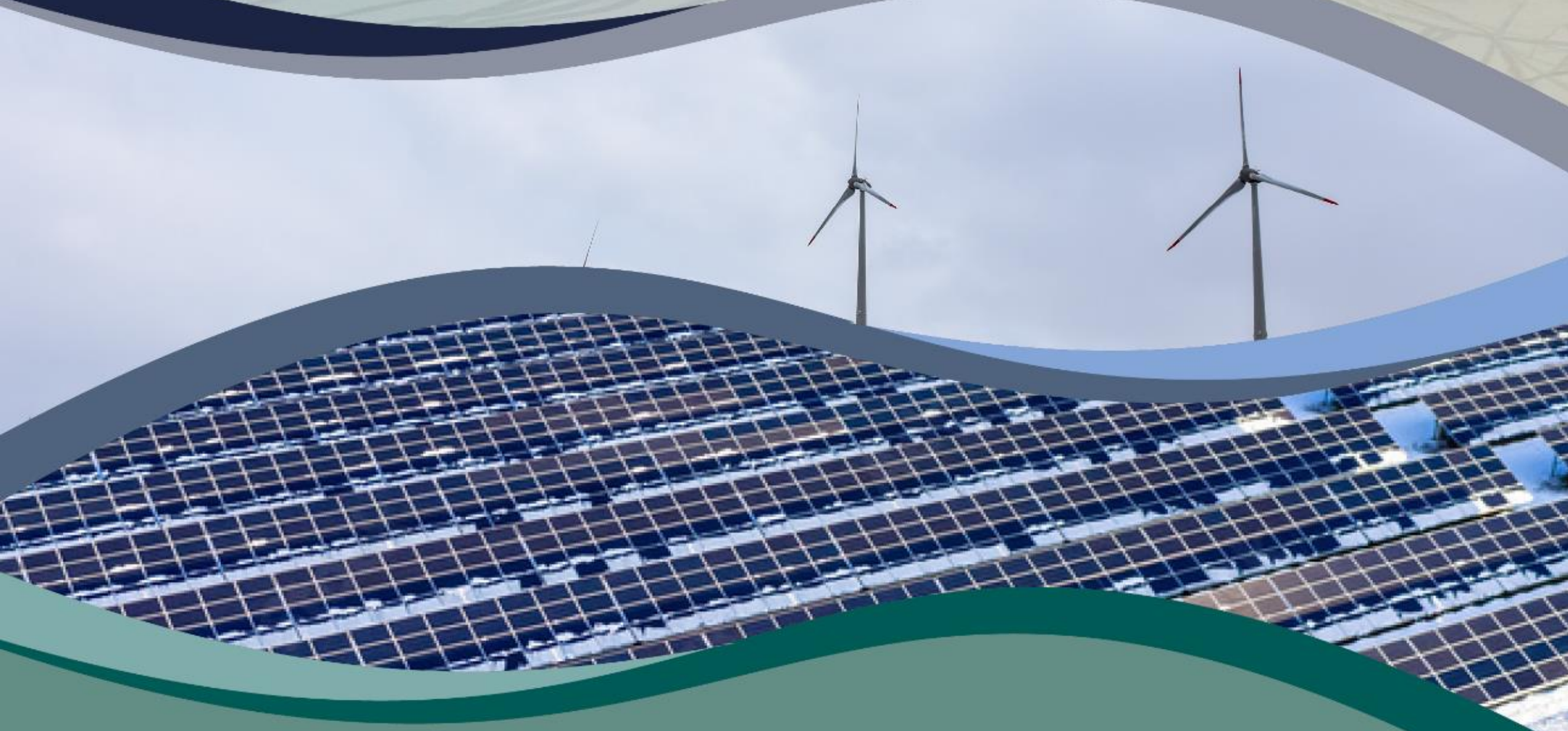


TABLE OF CONTENTS

INTRODUCTION

Background / Context

Previous technology and energy modelling activities that were conducted under the Ukraine-Denmark Energy Partnership (UDEPP), have shown that different stakeholders use varying data and assumptions regarding current and future energy technologies in Ukraine. This has the potential to cause discrepancies between different studies, and lead to differing or incompatible conclusions and recommendations in strategic documents. Most importantly, the full-scale Russian invasion of Ukraine has resulted in extensive damage done to the country's energy infrastructure.

Hence, under the Ukraine-Denmark Energy Partnership Programme (UDEPP), Ministry of Energy of Ukraine (MoE) have requested a fast development of a short-term and urgent energy technology catalogue for selected decentralized power generation capacities relevant for Ukraine that could be implemented quickly and facilitate enhanced security of distributed power supply for winter seasons, ideally already 2023-24, but certainly 2024-25.

The aim is that the catalogue will help local, regional, and national stakeholders, developers, companies, and others, to prioritize and select relevant power production technologies, in outlining framework and determine priorities for technology choices and attracting investments and donor assistance in the restoration and development of the power system of Ukraine in the coming winter seasons.

This urgent winterization technology catalogue will help 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 the longer term, a full-scale energy technology catalogue for Ukraine will be developed.

Both short-term and long-term technology catalogues, and corresponding technology specific performance parameters and costs, will provide a common and key foundation for energy and power sector planning and implementation activities.

In view of its acute purpose, to be ready for the upcoming 2023-24 winter and considering the short time available for the development and finalization of the first version of the catalogue, it has been necessary to narrow down the number of technologies as well as the range of details normally found in technology catalogues. This decision has been made in agreement with MoE. Hence, this urgent catalogue only includes data on carefully 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.

The purpose of this 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 decentralised power generation technologies is to map their potential for supplying electricity in the current Ukrainian context for winter seasons 2023-24/2024-25 which could be implemented to facilitate enhanced security of power supply.-

Thus, technologies included in this technology 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)

Possibility for bringing in operation within a short time frame (implementation speed). This includes evaluation of (A) time for planning and regulation approvals, B) time for acquisition of the plant (component and materials) and C) Technical installation time.

The resilience of selected technologies. This involves an evaluation of how well the technology performs at distribution system level, how well it could be camouflaged and sheltered, and the requirements (risks and skills) for keeping it in operation.

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, which could perform well in relation to the above-mentioned four principal criteria. The requirement on suitability for distributed production implies for example that only technology types which are reasonable to operate with capacities less than 60 MW are included.

As a starting point, eight power generation technology types (listed in the section below) have been addressed. Through a screening process, a limited number of specific “sub-type-technologies” has been identified as relevant to evaluate in the current context in Ukraine. The screening of the eight generic technology types ended up in a list of 22 sub-technologies shown below.

The evaluation of the four principal criteria for the different technologies is supported by assessment of 14 mostly descriptive and qualitative parameters listed in Table 1. In Appendix A: Methodology these 14 parameters are discussed, elaborating on why they are relevant to include in the assessments in this urgent technology catalogue and on how the qualitative parameters can be assessed at a three-level scale (good, medium, bad).

Each technology chapter will also include a brief technology description of the specific technology as well as a data sheet focused on data under today's conditions (e.g., 2024). The data sheets for the different technologies from the traditional Energy technology catalogue describing the technical and financial parameters can be found in Appendix F: Data sheets

Due to the short time frame available for the development of this catalogue, it will be continuously updated and still pending sub-technologies and documentation will be added in the next version.

Technologies included in the evaluation

The following technologies are assessed:

1. Gas power plants
   a) Gas Turbines, simple cycle, natural gas
   b) Gas engines, natural gas
   c) Gas engines, biogas directly from a green field biogas plant
2. Photovoltaics (PV)
   a) Rooftop PV on single family houses
   b,5b) Rooftop and ground mounted PV on public buildings (incl. hospitals) without batteries
   b) Rooftop and ground mounted PV on public buildings (incl. hospitals) with batteries
   c) PV utility scale, ground mounted without batteries,
   d) 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
   a) Onshore wind, parks 20 – 100 MW
   b) Onshore wind, parks 20 – 100 MW, used turbines
   c) Onshore wind, cluster of 3-5 turbines 3- 20 MW
   d) Domestic wind turbines
4. Coal power plants, lifetime extension (replacement of plant's equipment)
   a) Retrofitting existing plants, improving efficiency
5. Batteries - Lithium ion not small-scale UPS
   a) Grid-scale batteries, (capacity app. 2 MW -150MW, energy storage 2MWh - 500 MWh)
   b) Community batteries (capacity app. 40-150 kW, energy storage app. 40- 600-kWh)
6. Biogas
   - *no specific sub-technologies have been identified during the screening, but a gas engine fueled by biogas is included as a part of gas power*

7. Biomass cogeneration (CHP) technologies
    a) Wood pellets small Organic Rankine Cycle, 3 MWe
    b) Wood pellets medium, back pressure, 25 MWe
    c) Wood chips. small Organic Rankine Cycle, 3 MWe
    d) Straw small Organic Rankine Cycle, 3 MWe
    e) Straw medium, back pressure, 25 Mwe
8. Hydro Power, run of river
    a) Mini, Hydro Power, run of river
    b) Micro, Hydro Power, run of river

The structure of the technology chapters of the urgent technology catalogue

The format of the technology chapters comprises an overview of each technology group, showcasing the overarching findings of the respective technology segment. This is then followed by a detailed evaluation of each sub-technology, encompassing:

1. Brief technology description
2. Criteria evaluation based on the four defined criteria
3. Parameter evaluation based on the fourteen defined parameters
4. Data sheet in Excel 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.

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 to Ukrainian authorities, associations, and organizations working in the energy sector and its supply chains have been consulted during the screening process.

Based on the outcomes of the interviews with developers and experts, the typical process for power plants' installation, expected bottlenecks, and realistic possibilities to speed up the implementation process under the current condition are described.

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

Overview summarizing qualitative parameters across technologies and the criteria

An overview of the 14 parameters which are discussed and assessed in this technology catalogue is presented in Table 1. To make it easier to distinguish between criteria and parameter, each parameter (P) is given a number e.g., P1, P2, P3, as presented in Table 1

A description of the 14 parameters is in Appendix A: Methodology. It describes 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.

Parameters	Criteria	Evaluation levels:		
		Good	Medium	Bad
P1-Electricity production at wintertime	W	>75%	40%-75%	<40%
P2-Levelized Cost of Electricity (LCOE) short lifetime, winter production	C	low	Medium	high
P3-Levelized Cost of Electricity (LCOE) over lifetime		Low	Medium	high
P4-Distributed generation	R	<5 MW	5-20 MW	20-60 MW
P5-Regulation requirement in the project development process	Q	Quick and easy	In between	Lengthy
P6-Delivery time and availability of components and materials	Q	winter 2023/2024	winter 2024/2025	>2 years
P7-Requirements for logistics and transportation infrastructure	Q	low	Medium	high
P8-Technical installation time (after clearance)	Q	Short	Medium	Long
P9-Requirements for skilled staff in construction phase	Q	Low	Medium	High
P10-Grid balancing capacity	R	High	Medium	Low
P11-Requirements for electricity grid infrastructure	Q	Easy	Moderate	Challenging
P12-Requirements for skilled staff for operation and maintenance and for special spare parts	R	Low	Medium	High
P13-Possibility for camouflage and sheltering	R	High	Medium	Low
P14-Risk associated with fuel supply	R	Low	Medium	High

Table 1: Overview over the evaluation parameters and definition of the levels, column "Criteria" indicates which of the four principal criteria the parameter is contributing to is indicated by the letter (W, Q, R or C) in the. W: Winter Impact, Q: Implementation speed (Quick), R: Resilience in operation in UA context and C: Cost of generating the electricity (also referred to Levelized cost of electricity).

The four principal criteria are shown in Table2.The criteria are W: Winter Impact, Q: Implementation speed (Quick), R: Resilience in operation in UA context and C: Cost of generating the electricity (referred to as Levelized cost of electricity (LCoE)).

Each of the 14 parameters contribute to one of the four principal criteria. To give a comprehensive overview, this is shown both in Table 1 and in Table 2.

It can be seen in Table 2 in the column “parameter” that some of the criteria winter impact (W) and LCOE(C) consist of only one parameter while the criteria implementation speed(Q) and resilience(R) is evaluated based on 6 and 5 parameters.

Furthermore, some parameters can be given an absolute value (e.g., LCOE in Euro/kWh) which all in all makes it relatively easy to evaluate winter impact (W) and LCOE(C). For other criteria on the contrary, not all the parameters are assessed as absolute values.

Icon	Indicator	Parameter	Bad	Medium	Good
	Capacity in wintertime[1]	P1	Low production in wintertime	Medium production in wintertime	High production in wintertime
	Implementation speed[2]	P5, P6, P7, P8, P9, P11	Long time frame	Medium time frame	Short time frame
	Resilience[3]	P4, P10, P12, P13, P14	Low resilience	Medium resilience	High resilience
	Levelized cost of electricity[4]	P2,(P3)	High costs	Medium costs	Low costs

Table 2: Overview of which parameters contribute to which criteria and visualizing of the ratings, the more icons the better rating.

Implementation speed(Q) is based on the estimated time consumption for more different phases in the project development, represented by different parameters. Some of the parameters are measured in weeks and can thereby easily be summarized, this is the case for P5–*"Regulation requirement in the project development process"*, P6-" *Delivery time and availability of components and materials"* and P8-"*Technical installation time (after clearance)*", whereas P7-" *Requirements for logistics and transportation infrastructure"*, P9-" *Requirements for skilled staff in construction phase"* and P11-" *Requirements for electricity grid infrastructure"* are based on qualitative assessments, where the technologies are ranked relative to each other.

---

[1] Winter impact, defined as share of yearly production that can be delivered at 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 a.

When evaluating for Resilience(R), there is no absolute values of same unit for all the five parameters that influence the criteria. Therefore, a qualitative evaluation has been made for all parameters. The five parameters are for each technology evaluated relatively to its performance compared to the other technologies. Hereafter the five parameters are weighted. P4- *"Distributed generation"* and P13 - *"Possibility for camouflage and sheltering"* are assessed to be most important. Therefore, P4 and P13 are each given the weight 30%. P10 – *"Grid balancing capacity"* and P14–*" Risk associated with fuel supply"* are given 15 % weight each, while P12 - *"Requirements for skilled staff for operation and maintenance and for special spare parts"* are given 10% weight.

A general score is calculated as the simple average of the four criteria is illustrated in Figure 1.

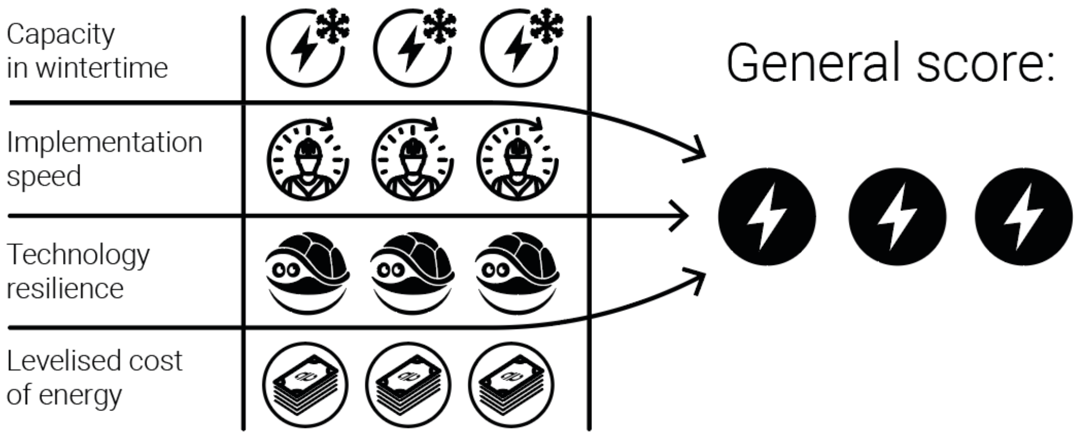


Figure 1: Example I. Visualization of criteria and general score

Technology frontpage

On each technology frontpage, the criteria evaluations are represented graphically with the following icons shown in Table 2 and Figure 1.

LCOE calculations

The method is described in Appendix B: LCOE calculations.

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.

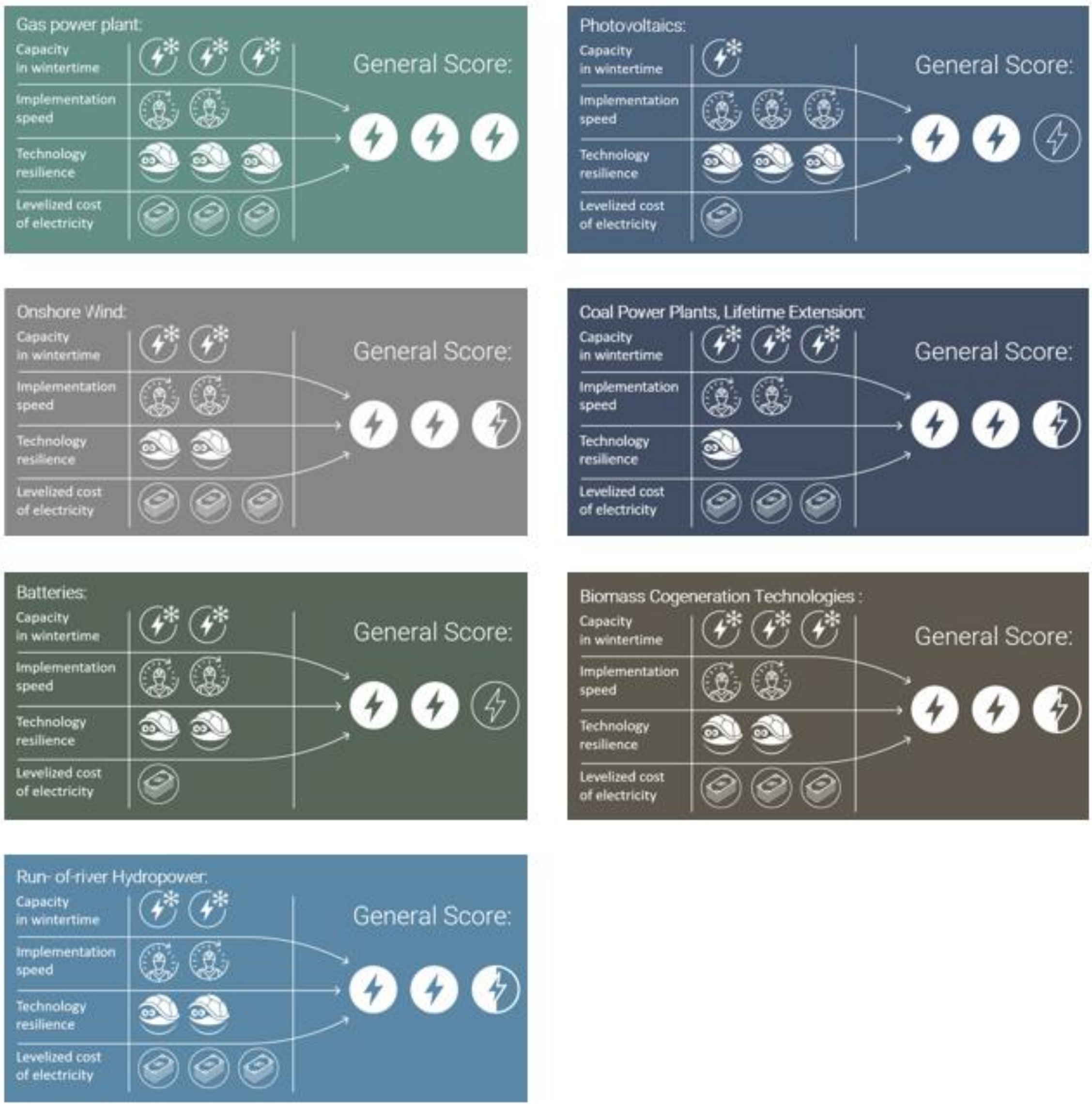


Figure 2: Technology Summaries, of best technologies in each category (Gas power plant: Gas engines, Photovoltaics: commercial and industrial PVs, Onshore wind: onshore parks >20MW, Coal power plants lifetime extension, Batteries: Li-ion Utility scale, biomass cogeneration technologies: medium CHP using wood pellets, Run-of-river hydropower: Hydro RoR micro)

In Table 3, a comprehensive evaluation of the sub-technology level is presented, focusing on the four principal criteria. Gas engines and turbines fueled by natural gas outperform the others, securing the highest overall score. The medium size wood pellet CHP also performs well, though slightly less so.

Gas turbines, gas engines and other thermal plants posses the greatest potential for supplying energy during winter time, contrary to for example solar PV which is limited during the winter season.

Gas engines, rooftop PV, domestic wind turbines and batteries could be implemented within half a year, while gasturbines, large PV, used onshore wind turbines, small size biomass CHPs and retrofittet coal are deemed realistic for implementation by 2024-25 due to short approval processes 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 fueled by straw/husk and wood chips, small size hydro power plants(RoR) and biogas engine solely supplyed by a 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.

Gas turbines and particular small scale gas engines also demonstrate a high level of resilience since they can be sheltered and protected more effectively due to their smaller size and flexibility in location. The same is true for batteries. Resilience have also been deemed high for small and medium scale PV and domestic wind turbines due to their size, it is assumed that they are not seen as an important target for firing.

When considering the cost effectiveness(LCoE) of the technologies over short time and only for the winter production gas technologies, onshore wind, coal retrofitting, all medium size biomass CHP and small hydro RoR plants turn out to be the most cost efficient.

When, on the other hand, the cost efficiency is seen over their full lifetime large-scale wind and with hydroelectric power, along, PV emerge as the most cost-effective solutions. Their renewable nature and lower operating costs contribute to significant returns over their operational lifetime.

Addittionally, for most of the technologies transformers connection the plant to the grid, are a critical component. Therefore, the delivery time for transformers is a critical parameter for most technologies. Stakeholders have mentioned that the delivery time for transformers are currently between 40 weeks and two years but that there are ways to acquire transformers faster. Therefore, a delivery time of two years for transformers is a risk but 2 years have not been assumed in the evaluations.

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
Capacity in wintertime	WWW	WWW	WWW	W	W	W	W	W
Implementation speed	QQ	QQ	Q	QQQ	QQQ	QQQ	QQ	QQ
Technology resilience	RR	RRR	RR	RRR	RRR	RRR	RR	RR
Levelized cost of electricity	CCC	CCC	CCC	C	C	C	C	C
General score (1-3)	2.5	2.8	2.3	2.0	2.0	2.0	1.5	1.5

Criteria evaluation	3.a. Wind onshore parks (>20MW)	3.a. Used wind onshore parks (>20MW)	3.a. Wind onshore cluster (4,2-20MW)	3.c. Wind domestic turbines (<100kW)	4. Coal retrofitting	5.a. Bat, Li-Ion Utility scale	5.b. Bat, Li-Ion community sca
Capacity in wintertime	WW	WW	WW	WW	WWW	WW	WW
Implementation speed	Q	QQ	Q	QQQ	QQ	QQ	QQQ
Technology resilience	RR	RR	RR	RRR	R	RR	RR
Levelized cost of electricity	CCC	CCC	CCC	C	CCC	C	C
General score (1-3)	2.0	2.3	2.0	2.3	2.3	1.8	2.0

Criteria evaluation	7.a. Wood pellets, CHP medium	7.b. Wood pellets, CHP Small	7c Wood Chips, CHP Medium	7d Wood Chips, CHP Small	7e Straw, CHP Medium	7f Straw, CHP Small	8.a. Small hydro, RoR	8.b. Micro hydro, RoR
Capacity in wintertime	WWW	WWW	WWW	WWW	WWW	WWW	WW	WW
Implementation speed	QQ	QQ	Q	QQ	Q	QQ	Q	QQ
Technology resilience	RR	RR	RR	RR	RR	RR	RR	RR
Levelized cost of electricity	CCC	CC	CCC	C	CCC	C	CCC	CCC
General score (1-3)	2.5	2.3	2.3	2.0	2.3	2.0	2.0	2.3

Table 3 Criteria evaluation matrix on sub technology level, for the implementation speed green indicate that the technology could be in operation in the winter 2023/2024(within less than 0,5 year), yellow indicate: could be in operation in the winter 2024/2025(within 1-1,5 year) and red that it would take more than 2 years to bring it in operation

Details for the four principal criteria

1.1.1 Winter impact (production at wintertime) (W)

Thermal power plants, which include gas, coal, and biomass-based systems, achieve the highest performance scores. 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 medium 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 power 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.

1.1.2 Implementation speed (Q)

When it comes to the speed of implementation, gas technologies, photovoltaic (PV) systems, domestic wind turbines, and battery storage systems achieve the highest ratings. These technologies can be deployed relatively quickly due to their matured technology, streamlined approval processes, and the availability of off-the-shelf solutions.

Onshore wind farms, various 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 and onshore wind turbines receive the lowest rating in terms of implementation speed. These projects often involve significant regulatory hurdles and lengthy planning processes, which can delay their implementation. Gas engines solely fueled supplyed by a greenfield project biogas plant is also 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 domestic 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, which 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.

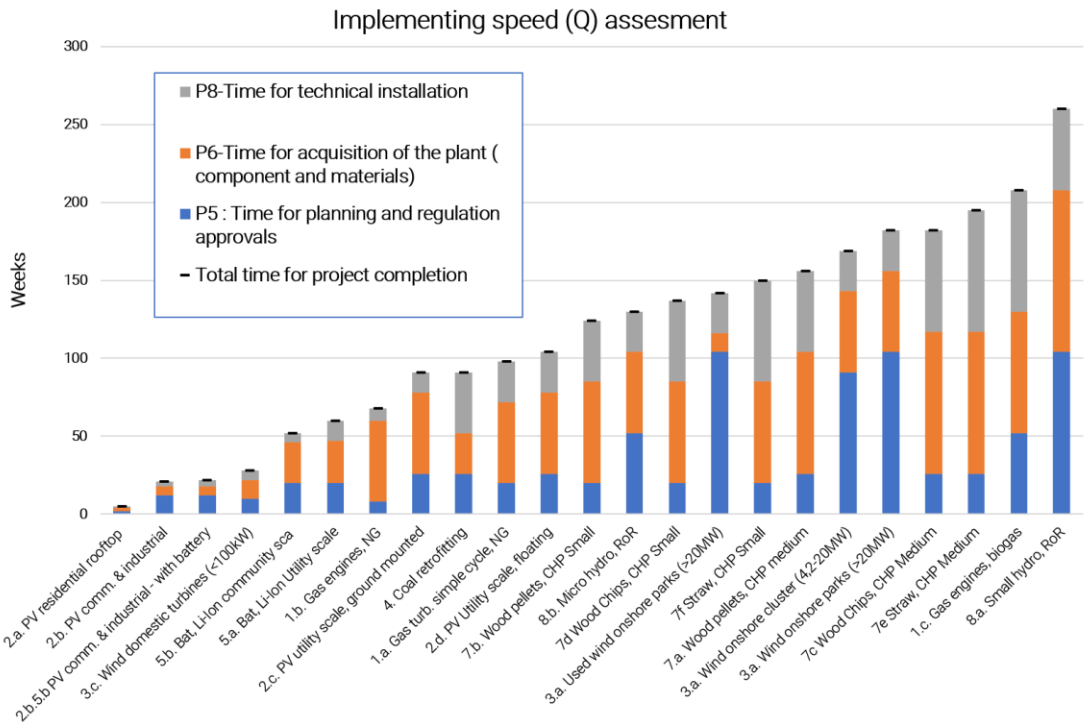


Figure 3: Assessment of the Implementing speed measured in weeks.

1.1.3 Resilience (R)

The resilience of an 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*.

Coal power plants have been given the lowest score in terms of resilience. The primary reason for this is their centralized nature. These large-scale plants are not distributed across multiple locations, making them more vulnerable to disruptions. A single well-placed attack could potentially take out the entire plant, significantly impacting power supply.

On the other end of the spectrum, small gas technologies and battery storage systems receive the highest rating. These systems can be sheltered and protected more effectively due to their smaller size and flexibility in location. Their distributed nature also contributes to their resilience, as damage to one part of the system does not necessarily impact the entire network.

Small-scale technologies, such as rooftop solar panels and domestic wind turbines, also receive high scores. While these systems 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.

Large-scale wind and solar farms also receive high scores since due to their dispersed layout it would require multiple attacks to take them out entirely. Moreover, the transformer stations connecting these farms to the high voltage power grid could be camouflaged or protected, for example, by a concrete ceiling.

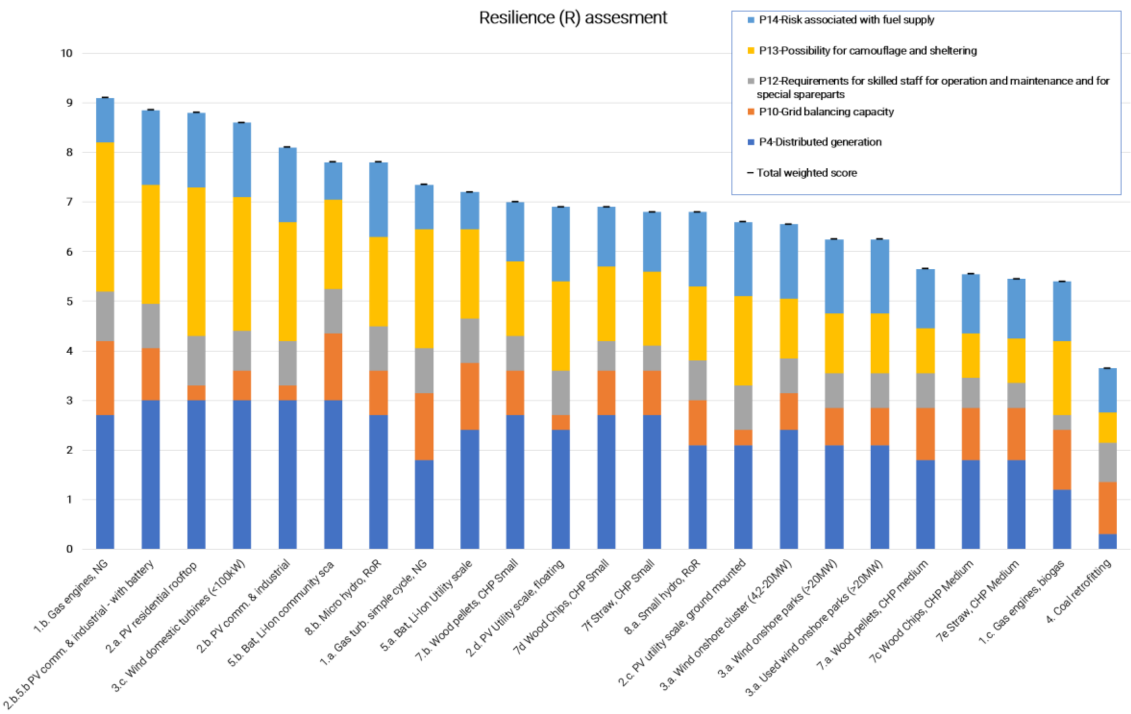


Figure 4: Overview of resilience assessment all sub-technologies, the parameters are weighted.

1.1.4 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. Financial cost and cost of CO2 are not included in the short term LCOE.

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 wind power also exhibit competitive short-term LCOEs.

On the other hand, all solar power technologies exhibit high short-term LCOEs. This is due to their limited power generation capacity during the winter months, coupled with their high initial investment costs.

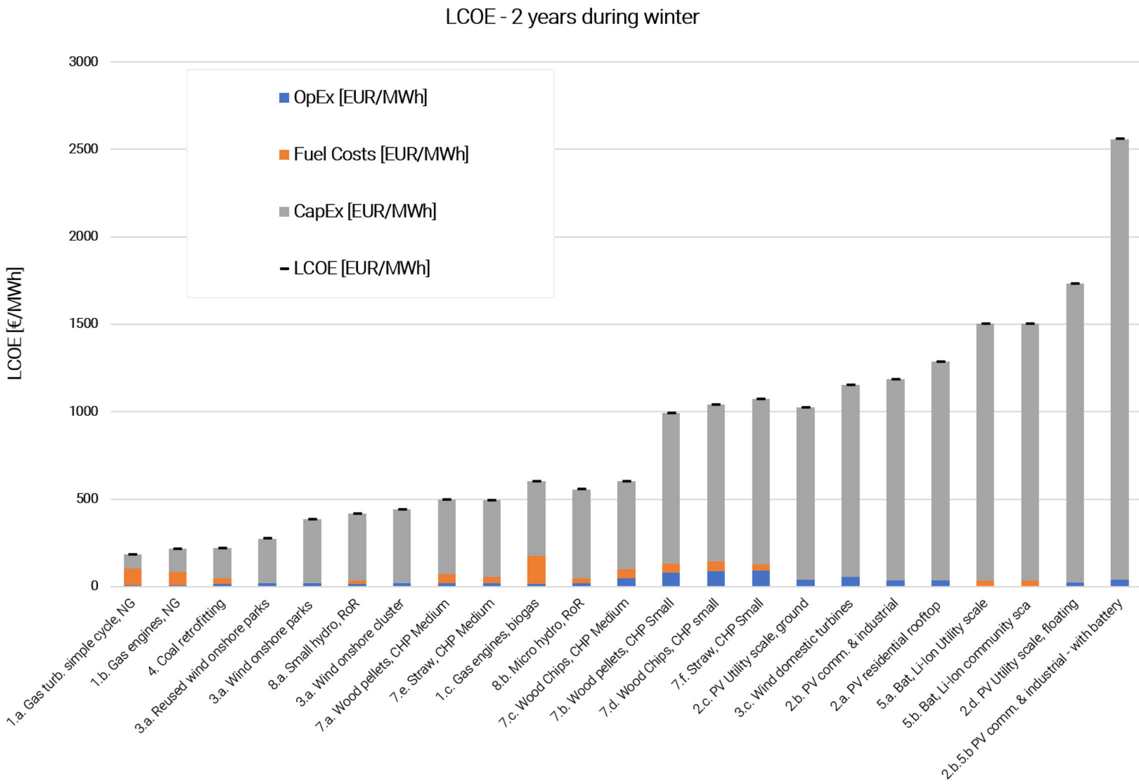


Figure 5: LCOE for wintertime production over 2 years

When considering the LCOE over the full lifetime of the technologies, shown in *Figure 6*, the picture changes. Large-scale wind and solar power, 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, coal power plants and commercial scale rooftop PV systems also demonstrate competitive lifetime LCOEs. Despite the environmental concerns associated with coal power, its substantial power output results in lower costs over the long term.

The remaining thermal power plants, along with batteries and domestic wind turbines, exhibit relatively high LCOEs. These technologies face challenges such as high fuel costs (for thermal plants) and high investment costs relative to their output (for batteries and domestic wind turbines), resulting in higher costs over the long term.

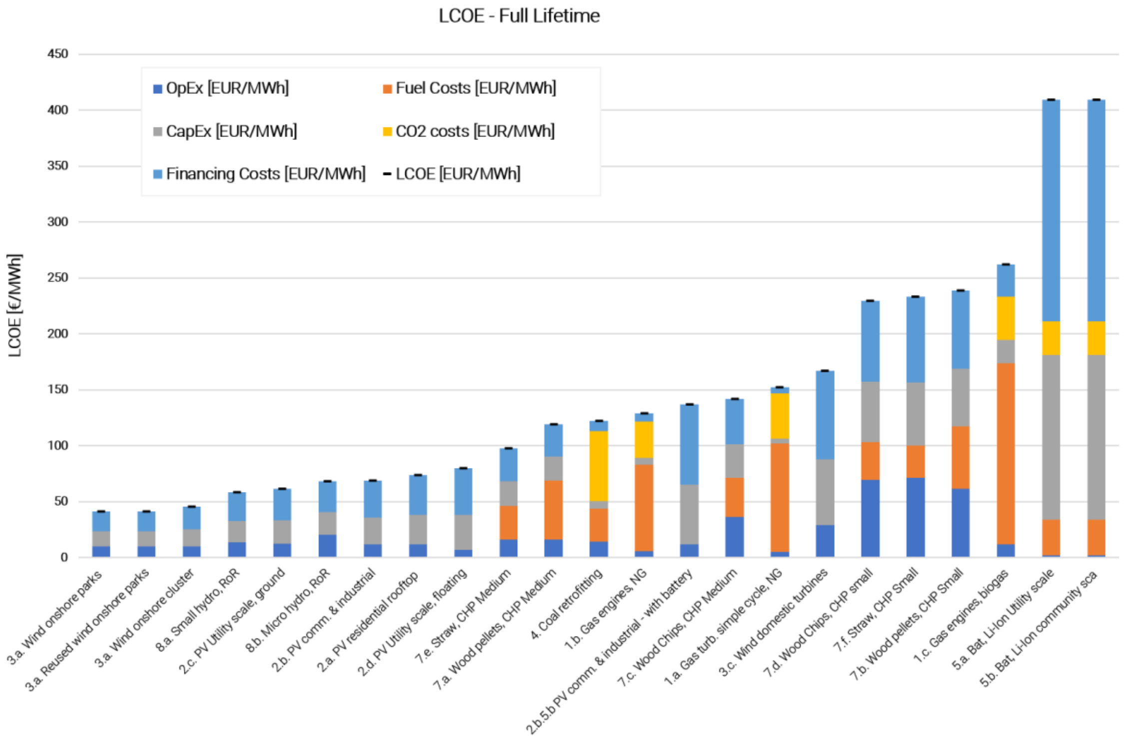


Figure 6: LCOE total production over the lifetime

1.1.4 Parameter evaluation overview

In Table 4 an overview of the rating of all parameters for all sub-technologies are shown.

Parameter 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	291	398	1178	2972	5961	2740	2357	4045
P3-Levelized Cost of Electricity (LCOE) over lifetime	152	129	262	74	137	69	61	80
P4-Distributed generation	5-40 MW	1-10 MW	1-10 MW	0,006 MW	0,1 MW	0,1 MW	40 MW	10 MW
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	Medium
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	Moderate	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 potential	High potential	Medium potential	High potential	High potential	High potential	Medium potential	Medium potential
P14-Risk associated with fuel supply	Medium risk	Medium risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk

Parameter evaluation	3.a. Wind on-shore parks (>20MW)	3.a. Used wind on-shore parks (>20MW)	3.a. Wind onshore cluster (4,2-20MW)	3.c. Wind domestic turbines (<100kW)	4. Coal retro-fitting	5.a. Bat, Li-Ion Utility scale	5.b. Bat, Li-Ion com-munity scale
P1-Electricity production at wintertime	50%	50%	50%	50%	>75%	50%	50%
P2-Levelized Cost of Electricity (LCOE) short lifetime, winter production	881	622	1010	2637	454	3491	3491
P3-Levelized Cost of Electricity (LCOE) over lifetime	41	41	46	167	122	410	410
P4-Distributed generation	>20 MW	>20 MW	4,2-20 MW	0,1 MW	500 MW	5-150 MW	40-200 kW
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	Medium-term	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 potential	Medium potential	Medium potential	High potential	Low potential	Medium potential	Medium potential
P14-Risk associated with fuel supply	Low risk	Low risk	Low risk	Low risk	Medium risk	Medium risk	Medium risk

Parameter evaluation	7.a. Wood pellets, CHP medium	7.b. Wood pellets, CHP Small	7c Wood Chips, CHP Medium	7d Wood Chips, CHP Small	7e Straw, CHP Medium	7f Straw, CHP Small	8.a. Small hydro, RoR	8.b. Micro hydro, RoR
P1-Electricity production at wintertime	>75%	>75%	>75%	>75%	>75%	>75%	50%	50%
P2-Levelized Cost of Electricity (LCOE) short lifetime, winter production	1075	2152	1279	2250	1088	2352	929	1244
P3-Levelized Cost of Electricity (LCOE) over lifetime	119	239	142	230	98	233	59	68
P4-Distributed generation	20-35 MW	3-3,15 MW	20-35 MW	2,85-3 MW	24-26 MW	2,95-3,10 MW	10-100 MW	1-10 MW
P5-Regulation requirement in the project development process	In between	In between	In between	In between	In between	In between	Lengthy	Lengthy
P6-Delivery time and availability of components and materials	Lengthy and complicated	Lengthy and complicated	Lengthy and complicated	Lengthy and complicated	Lengthy and complicated	Lengthy and complicated	Lengthy and complicated	In between
P7-Requirements for logistics and transportation infrastructure	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Low
P8-Technical installation time (after clearance)	Lengthy and complicated	Medium-term	Lengthy and complicated	Lengthy and complicated	Lengthy and complicated	Lengthy and complicated	Lengthy and complicated	Medium-term
P9-Requirements for skilled staff in construction phase	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P10-Grid balancing capacity	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
P11-Requirements for electricity grid infrastructure	Moderate	Easy	Moderate	Easy	Moderate	Easy	Moderate	Moderate
P12-Requirements for skilled staff for operation and maintenance and for special spare parts	Medium	Medium	Medium	Medium	Medium	Medium	Low	Low
P13-Possibility for camouflage and sheltering	Low potential	Medium potential	Low potential	Medium potential	Low potential	Medium potential	Medium potential	Medium potential
P14-Risk associated with fuel supply	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk

Table 4: Parameter evaluation matrix

Cross cutting issues as issues related to the grid as operational challenges in the UA grid system and challenges related to integration of renewable energy technologies, financial issues and issues related to transformers are outlined in appendix C.

EVALUATION OF CHOSEN TECHNOLOGIES

In this section, technologies are evaluated regarding criteria and parameters.

Gas Power Plants

GAS POWER PLANTS

Criteria evaluation	1.a. Gas turb. simple cycle, NG	1.b. Gas engines, NG	1.c. Gas engines, biogas
Capacity in wintertime	WWW	WWW	WWW
Implementation speed	QQ	QQ	Q
Technology resilience	RR	RRR	RR
Levelized cost of electricity	CCC	CCC	CCC
General score (1-3)	2.5	2.8	2.3

This chapter covers three types of gas power plants:

- Gas turbines, simple cycle, fueled by natural gas
- Gas engine, fueled by natural gas
- Gas engine, fueled by biogas (not upgraded), solely supplied by a greenfield project biogas plant.

Both gas turbines and gas engines can be manufactured across a broad spectrum of sizes, spanning from a few kilowatts to multiple megawatts. Specifically for this project, 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.

1.1.5 Gas turbines, simple cycle

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), compressor, combustion chamber, and a generator; see Figure 7.

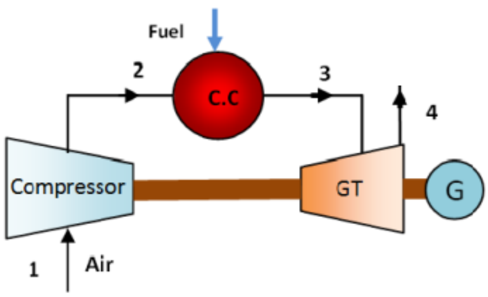


Figure 7: Process diagram of a SCGT[1]

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 injection 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%).

Criteria evaluation

Criteria evaluation	1.a. Gas turb. simple cycle, NG
Capacity in wintertime	WWW
Implementation speed	QQ
Technology resilience	RR
Levelized cost of electricity	CCC
General score (1-3)	2.5

Table 5: Gas turbines, simple cycle – criteria evaluation matrix

Winter impact (production at wintertime)

Gas turbines will be able to provide a significant contribution to the Ukrainian power system during wintertime. Gas power plants are dispatchable, and it is realistic for them to generate with a high capacity factor approaching, 90-100%, during the winter if deemed necessary.

Implementing speed

The implementation time is very dependent on 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 would typically be close to two years.

Resilience

The resilience of gas turbines can be attributed to two key factors. Firstly, their modest capacity enables the dispersion of gas turbines over a wide geographic area. This dispersion minimizes vulnerability to potential air strikes from artillery, missiles, or drones. Secondly, the relatively small footprint of gas turbines allows for installation within bunkers, which can be effectively camouflaged to enhance their security. Potential disruptions to the gas supply, either in select regions of Ukraine or on a national level, caused to terrorist attacks, makes up a risk that cannot be neglected.

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

Due to their low upfront costs 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.

Data sheet

In Appendix F

1.1.6 Gas engine

The section covers

- Gas engine, fueled by natural gas.
- Gas engine, fueled by not upgraded biogas, solely supplyed by a greenfield project biogas plant.

There is no difference in the gas engine technology. The biogas plant technology is described in the chapter Biogas.

.

Brief technology description

The evaluation includes a gas engine fueled by natural gas and

A gas engine for co-generation of heat and power drives an electricity generator for the 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 kW_e to 10 MW_e.

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 a high heat production and highest possible overall efficiency.

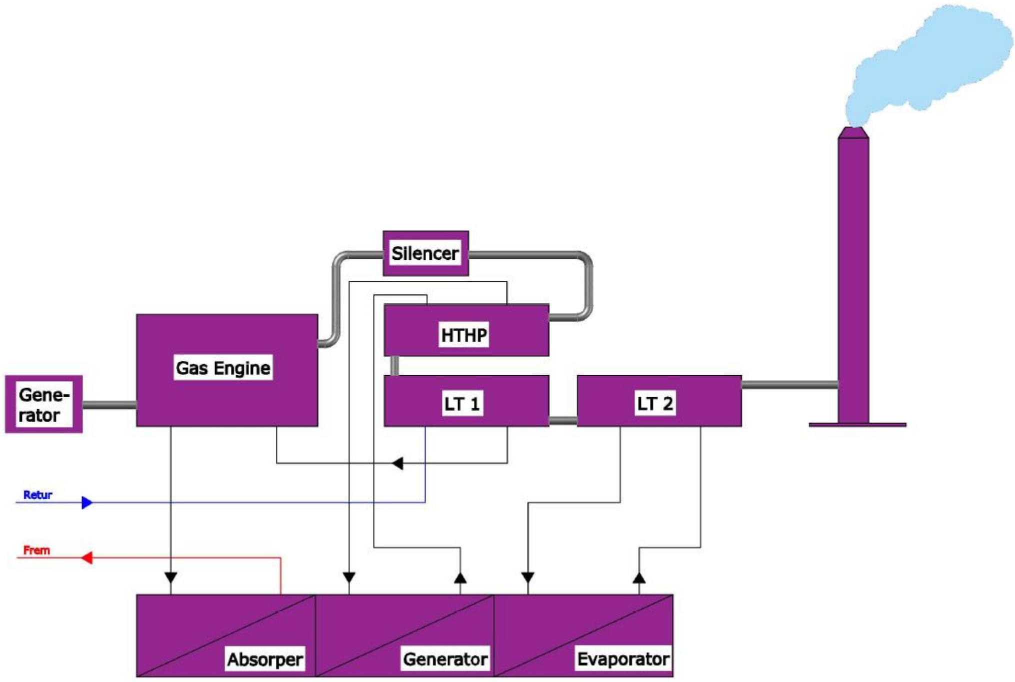


Figure 8: Gas engine cogeneration unit

Criteria evaluation

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

Criteria evaluation	1.b. Gas engines, NG	1.c. Gas engines, biogas
Capacity in wintertime	WWW	WWW
Implementation speed	QQ	Q
Technology resilience	RRR	RR
Levelized cost of electricity	CCC	CCC
General score (1-3)	2.8	2.3

Table 6: Gas engines – criteria evaluation matrix

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 factor, approaching 90-100%, if needed.

Implementing speed

The implementation timeline hinges significantly on the project's size. Technology delivery is estimated at around 1 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 streamlined to less than 1.5 years.

Resilience

The resilience of gas engines is linked to two factors. Firstly, their moderate 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. The risk of potential disruptions to the gas supply, whether in specific regions of Ukraine or nationally due to terrorist attacks, is a significant concern that cannot be overlooked.

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 three times higher than that of utility scale wind and solar power.

1.1.7 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.

Parameter 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	291	398	1178
P3-Levelized Cost of Electricity (LCOE) over lifetime	152	129	262
P4-Distributed generation	5-40 MW	1-10 MW	1-10 MW
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	Moderate
P12-Requirements for skilled staff for operation and maintenance and for special spare parts	Low	Low	High
P13-Possibility for camouflage and sheltering	High potential	High potential	Medium potential
P14-Risk associated with fuel supply	Medium risk	Medium risk	Low risk

Table 7: Gas Power – parameters evaluation matrix

P1: Electricity production at wintertime (W)

Gas turbines and gas engines, rely on gas as a 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 refurbished, 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 refurbishment is planned to be done during the summer, where the need for the plant is greatly lower. Forced outages can happen for multiple reasons, but typically occurs due to some form of breakdown, which occurs during production.

As mentioned, the need for a gas engine or turbine, is greatly 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, gas engines and turbines also compete 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 gas turbine and engine 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 gas engine and turbine, will operate with 3.750 full load hours during the wintertime. This corresponds to the annual FLH of a 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. If Ukrainian power plants do not cannibalize on each other, due to missing capacity caused by Russian terror, then the FLH can be expected to be higher. In summary, gas turbines and engines may be considered a great power source during the wintertime.

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 assess. For a gas turbine with a simple cycle, the LCOE is expected to be 290 €/MWh, compared to about 400 €/MWh for the gas engine.

The natural gas engine and turbines stand out because the majority of their life-time expenditure is caused by fuel consumption, whereas the investment cost is relatively low, and so is the cost for operation and maintenance. As less fuel is consumed, as the operational period is significantly shorter, the fuel costs are proportionately lower in comparison to the investment cost, in regard to the LCOE.

Gas engines utilizing biogas, would have slightly higher investment cost than that of the natural gas engine, as it need to be retrofitted a little to use biogas as a fuel, which also contains a large portion of CO_2. Furthermore, the fuel is a little more costly. This drives the price 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 is expected to be approx. 150 €/MWh. For the gas engine the LCOE is expected to be about 130 €/MWh. This two-three times higher than utility scale solar and wind power but less than the biomass technologies included and the small-scale wind and solar technologies. Fuel costs make up the vast majority of costs and therefore obviously, the generation cost from gas technologies, are highly sensitive to the fuel price developments of gas. The projected LCOE assumes a long-term gas price of 35 €/MWh (HHV), assuming LNG will set 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 5MW, the gas turbines can generally be considered to have a medium distributed generation capacity. As gas engines have a power generation capacity of 1-5MW, the gas engine can be considered to be easy to distribute. Given the current situation in Ukraine, there are several compelling reasons to favor distributed installations. These installations, located near demand centers, 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, turbine and the biogas engine, the regulation requirement in the project development process is considered to be quick and easy. This is due to the fact, that these three technologies come in modular builds, which are well known and are pre certified for operation. Furthermore, they do not require a lot of space, which makes the planning proces easier as the building in which the technologies will be placed, has a smaller impact on the local environment. This means that an evironmental impact assesment report probably will not be needed.

For the natural gas engine, turbine and the biogas engine, the time spent on planning and regulation approvals is estimated to be arround 20 weeks.

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 when 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 start 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, which 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 0,5-1MW 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.

P7: Requirements for logistics and transportation infrastructure (Q)

This unit and the components needed for the construction typically requires transport by equipment of the size of a semitruck, which requires a road. This means that the gas engine and turbine, has a low requirement for logistics and transportation infrastructure, as roads and semitrucks are easily available.

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

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

Smaller gas engines with a capacity up to about 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.

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

During the construction phase, general laborers, heavy equipment operators, concrete workers, welders, plumbers, electricians, HVAC technicians and safety specialist workers are required. These laborer 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 laborers from Ukraine. During the interviews, it was established that the education for assembling a small gas engine or turbine plant, might take some month, which 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.

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 10MW, the requirements for connecting the gas turbines to the grid is higher than that of a gas engine. Which is why the requirement for the coupling of the gas turbine to the grid, is considered to be moderate, as they can be connected to almost any grid, as long as 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 1MW 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.

P13: Possibility for camouflage and sheltering (R)

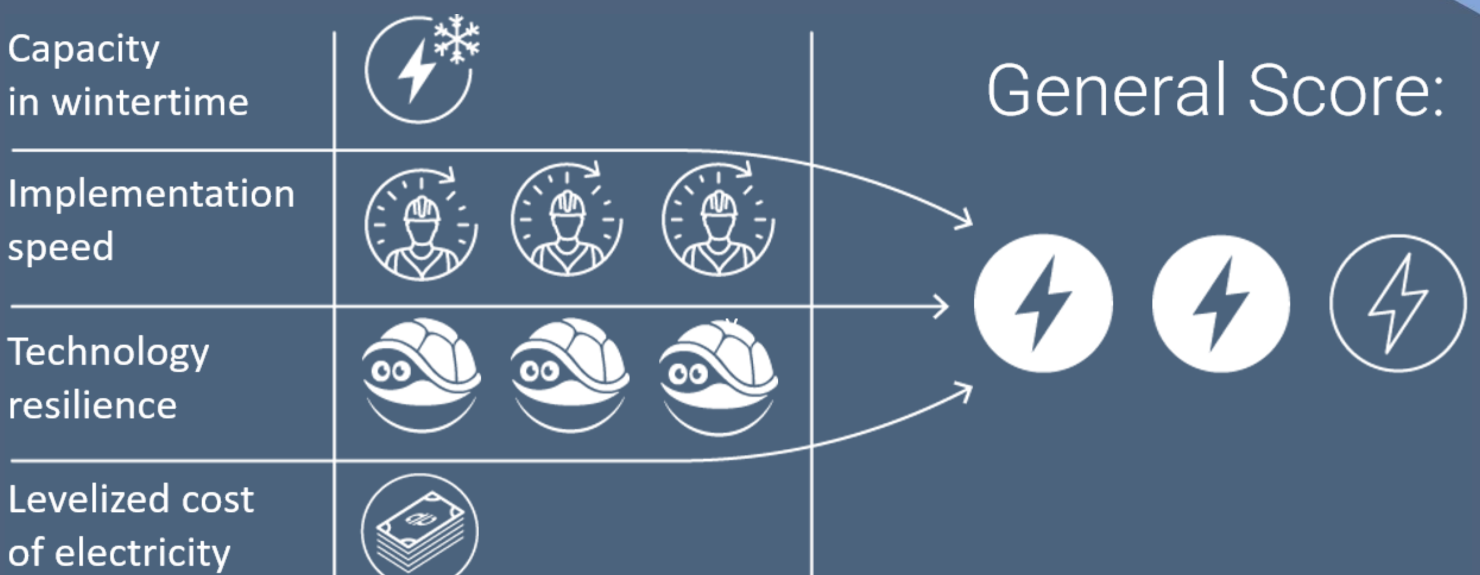
Gas turbines and engines have a small footprint, which means that they can easily be put into a bunker, that can be camouflaged. Therefore, the possibility for camouflage and sheltering is rated to be of high potential.

P14: Risk associated with fuel supply (R)

As Russia has invaded Ukraine and uses the gas supply as a leverage on European countries, the risk associated with gas as a fuel supply is considered as a medium level, because European countries suddenly might not have any available gas to send to Ukraine via the gas lines. But Ukraine also has a considerable gas production, which they might utilize for the gas engines and turbines, but the fuel lines might be subjected to Russian terror which might lower the availability of gas for shorter periods of time, until the gas pipes have been fixed again. If the availability of gas is lowered, some gas engine or turbine plants might have to shut down for smaller periods of time.

If the gas engines utilize biogas, the risk associated with the fuel supply is expected to be low, as the biogas stems from Ukraine's own biogas facilities to which the engines are typically connected directly. The biogas facilities are expected to use agricultural waste products, which there is an abundance of in Ukraine.

Photovoltaics



PHOTOVOLTAICS

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
Capacity in wintertime	W	W	W	W	W
Implementation speed	QQQ	QQQ	QQQ	QQ	QQ
Technology resilience	RRR	RRR	RRR	RR	RR
Levelized cost of electricity	C	C	C	C	C
General score (1-3)	2.0	2.0	2.0	1.5	1.5

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 is explaining the fundamental technical details that is general for PV. Hereafter, each technology is outlined in individual sub-chapters consisting of a brief technology description, criteria evaluation, and data sheet in annex E. The parameter evaluation for each technology, conversely, is conducted collectively, considering their shared similarities. Where possible a distinction between the technologies is made.

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 or 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).

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 (22% efficiency). 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 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 Wind Atlas. The map is shown in Figure 99, 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.

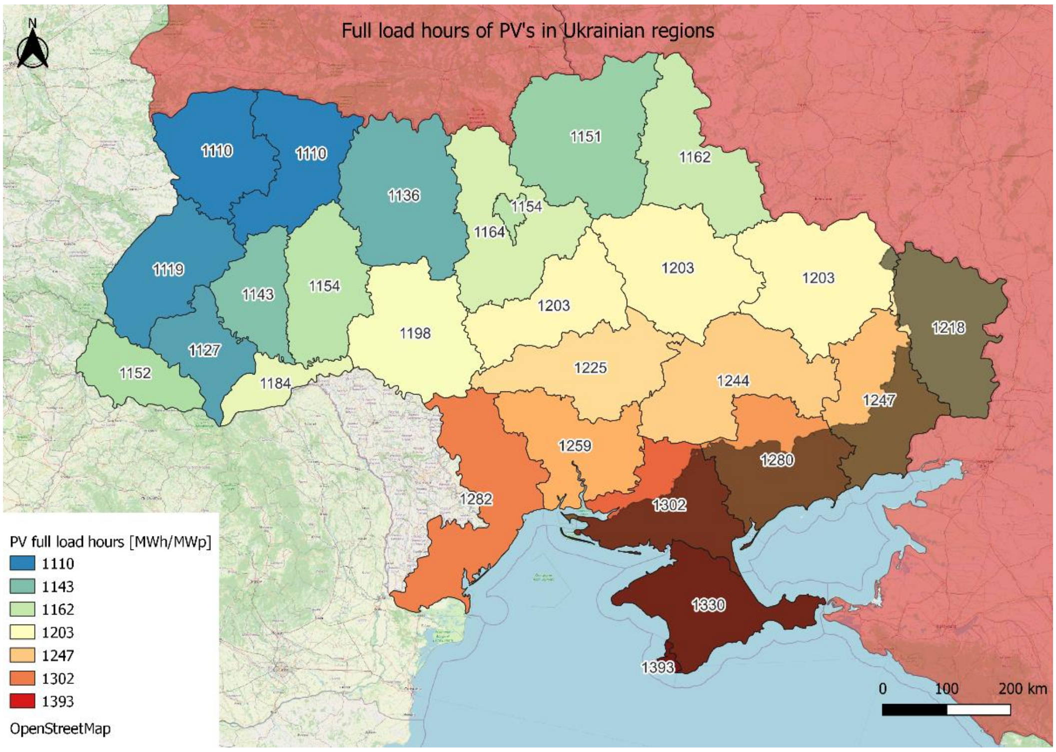


Figure 9: Expected PV generation (MWh per MW installed capacity)) in different regions of Ukraine. An annual production of 1200 MWh/MW corresponds to a capacity factor of 14%. The maps are set up calculating the generalized power generation from photovoltaics, in the different Ukrainian regions, Global Solar Atlas covering the period between 1994-2018 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 which contribute 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.

1.1.8 PV residential rooftop

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 10kW.

Criteria evaluation

Criteria evaluation	2.a. PV residential rooftop
Capacity in wintertime	W
Implementation speed	QQQ
Technology resilience	RRR
Levelized cost of electricity	C
General score (1-3)	2.0

Table 8 PV residential rooftop – criteria evaluation matrix

Winter impact (production at wintertime)

Solar PV generally produce more during summertime than during the winter period[5]. Only 30% of the total production is in winter. The average capacity factor during winter is app. 8%, while the annual capacity factor of 14%. The potential PV generation differs across the country which for wintertime production is shown on the map in Figure 12 Figure 10. This is consistent for PV technology and does not differ across various sub-technologies within the PV category.

Implementing speed (Q)

In principle a residential PV can be commissioned less than 5 weeks after the decision have been taken. Since, it can be installed within a week. While the preparation processes including inspection and calculation to conclude if the construction of the roof is appropriate for installing the modules could also conducted in a day or two. Furthermore, there will be a delivery time, which could also be assumed to be relatively short and less than 2 weeks. It is not necessary to include time spent obtaining permits, then,

[5] October to March

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 is achieved by signing electricity purchase and sale agreements under the self-generation mechanism, 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 in operation.

Resilience (R)

Residential PV showcase considerable 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.

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

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

Data sheet

In Appendix F

1.1.9 PV commercial and public, rooftop and ground mounted

Brief technology description

PV commercial and public, rooftop and ground mounted refers to a solar PV system installed on the roof of or at 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 solar panels, inverters, grid connections, mounting structures, monitoring equipment 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. It is assumed that the total capacity of the PV modules in a residential system is up to 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.

Criteria evaluation

Criteria evaluation	2.b.5.b PV comm. & industrial - with battery	2.b. PV comm. & industrial
Capacity in wintertime	W	W
Implementation speed	QQQ	QQQ
Technology resilience	RRR	RRR
Levelized cost of electricity	C	C
General score (1-3)	2.0	2.0

Table 9: PV commercial, industrial, and public rooftop – criteria evaluation matrix

Winter impact (production at wintertime)

Solar PV typically generates more power in the summer compared to the winter period[6], with only around 30% of the total production occurring in winter. However, the capacity factor varies between the regions. The average capacity factor during winter is approximately 8%, while the average annual capacity factor is 14%. This is consistent for PV technology and does not differ across various sub-technologies within the PV 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 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 moderate 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

[6] October to March

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.

Combining with batteries improves the resilience. Furthermore, the batteries can be installed underground and or be sheltered and camouflaged, despite a considerable demand for cooling.

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

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

Data sheet

In Appendix F

1.1.10 PV utility-scale

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 acres of land.

Criteria evaluation

Criteria evaluation	2.d. PV Utility scale, floating
Winter impact	W
Implementing speed	QQ
Resilience	RR
Cost (LCOE, wintertime 2 years lifetime)	C
General score (1-3)	1.5

Table 10: PV utility-scale – criteria evaluation matrix

Winter impact (production at wintertime)

Solar PV typically generates more power in the summer compared to the winter period[7], with only around 30% of the total production occurring in winter. However, the capacity factor varies between the regions. The average capacity factor during winter is approximately 8%, while the average annual capacity factor is 14%. This is consistent for PV

[7] October to March

technology and does not differ across various sub-technologies within the PV category.

Implementing speed (Q)

The implementation speed set to moderate, although that the development of a utility-scale solar PV farm involves several key steps, including screening the electrical grid's capacity, identifying potential sites, securing land rights, designing the solar park, obtaining permits, negotiating power purchase agreements, securing financing, procuring equipment, and finally, construction and operations.

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 installations varies, and Ukraine's infrastructure poses challenges. 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 idea to operation is a little less than 2 years.

Resilience (R)

The resilience of 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.

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

Utility scale ground mounted PV technology exhibit among the least competitive Levelized cost of electricity (LCOE) when analyzed over the short term (2 years) and only for wintertime production. This is due to the high capital cost and low production at wintertime. Seen over the entire lifetime, the LCOE for PV is on the other hand is among the lowest among the technologies analyzed.

Data sheet

In Appendix F

1.1.11 Floating utility-scale PV

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. If, they will be placed on the surface of the dam of a hydro power plants, transformers and grid can be shared which is an advantage for the economy. The key difference to ground mounted Utility scale PV system is the specially designed floating structures or platforms are used to support solar panels on the water's surface.

Inverter Systems: Inverters are employed to convert the direct current (DC) electricity generated by the solar panels into alternating current (AC) suitable for the grid. Grid Connection: Floating solar installations are typically connected to the electrical grid, allowing the generated electricity to be distributed and utilized as needed.

Criteria evaluation

Criteria evaluation	2.d. PV Utility scale, floating
Capacity in wintertime	W
Implementation speed	QQ
Technology resilience	RR
Levelized cost of electricity	C
General score (1-3)	1.5

Table 11 PV utility-scale floating - criteria evaluation matrix

Winter impact (production at wintertime)

Solar PV typically generates more power in the summer compared to the winter period[8], with only around 30% of the total production occurring in winter. However, the capacity factor varies between the regions. The average capacity factor during winter is approximately 8%, while the average annual capacity factor is 14%. This is consistent for PV technology and does not differ across various sub-technologies within the PV category.

Implementing speed (Q)

The implementation speed set to moderate, although that the development of a floating utility-scale solar PV involves several key steps, including screening the electrical grid's capacity, identifying potential sites, securing land rights, designing, obtaining permits, negotiating power purchase agreements, securing financing, procuring equipment, and finally, construction and operations.

[8] October to March

It is assumed it could be a challenge to hirs experienced construction companies because the floating PV is a relatively new technology. Therefore, it is assumed that it takes a little longer to construct the floating solar park, but that it can be within a time frame of approximately 8 months. Challenges include delays in grid connection, shortage of skilled engineers, and transportation obstacles. The delivery time for solar PV installations varies, and Ukraine's infrastructure poses challenges. Integration into the electricity grid requires well-developed infrastructure but could faster if placed on a dam of a hydro plant, where the installations sufficient capacity is already available.

However, it is concluded that the total period from idea to operation is a little 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 centers 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.

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

Utility scale floating PV technology exhibit among the least competitive Levelized cost of electricity (LCOE) when analyzed over the short term (2 years) and only for wintertime production. This is due to the high capital cost and low production at wintertime. Seen over the entire lifetime, the LCOE for floating PV is on the other hand is in the middle among the technologies analyzed.

Data sheet

In Appendix F

1.1.12 PV parameter evaluation

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

Parameters	2.a. PV residential rooftop	2.b.5.b PV comm. & industria	2.b. PV comm. & industrial	2.c. PV utility scale, ground	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	2972	5961	2740	2357	4045
P3-Levelized Cost of Electricity (LCOE) over lifetime	74	137	69	61	80
P4-Distributed generation	0,006 MW	0,1 MW	0,1 MW	40 MW	10 MW
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	Medium
P8-Technical installation time (after clearance)	Quick and easy	Quick and easy	Quick and easy	Quick and easy	Medium-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	Challenging	Challenging
P12-Requirements for skilled staff for operation and maintenance and for special spareparts	Low	Low	Low	Low	Low
P13-Possibility for camouflage and sheltering	High potential	High potential	High potential	Medium potential	Medium potential
P14-Risk associated with fuel supply	Low risk	Low risk	Low risk	Low risk	Low risk

Table 12 Photovoltaic technologies - parameter evaluation matrix

P1 Electricity production at wintertime:

Solar PV generally produce more during summertime than during the winter period[9]. Only 30% of the total production is in winter. The average capacity factor during winter is app. 8%, while the annual capacity factor of 14%. Obviously, the production depends on the specific location. Figure 10 shows, the expected annual wintertime PV generation in full load hours (FLH: MWh per MW installed capacity) in different regions of Ukraine.

[9] October to March

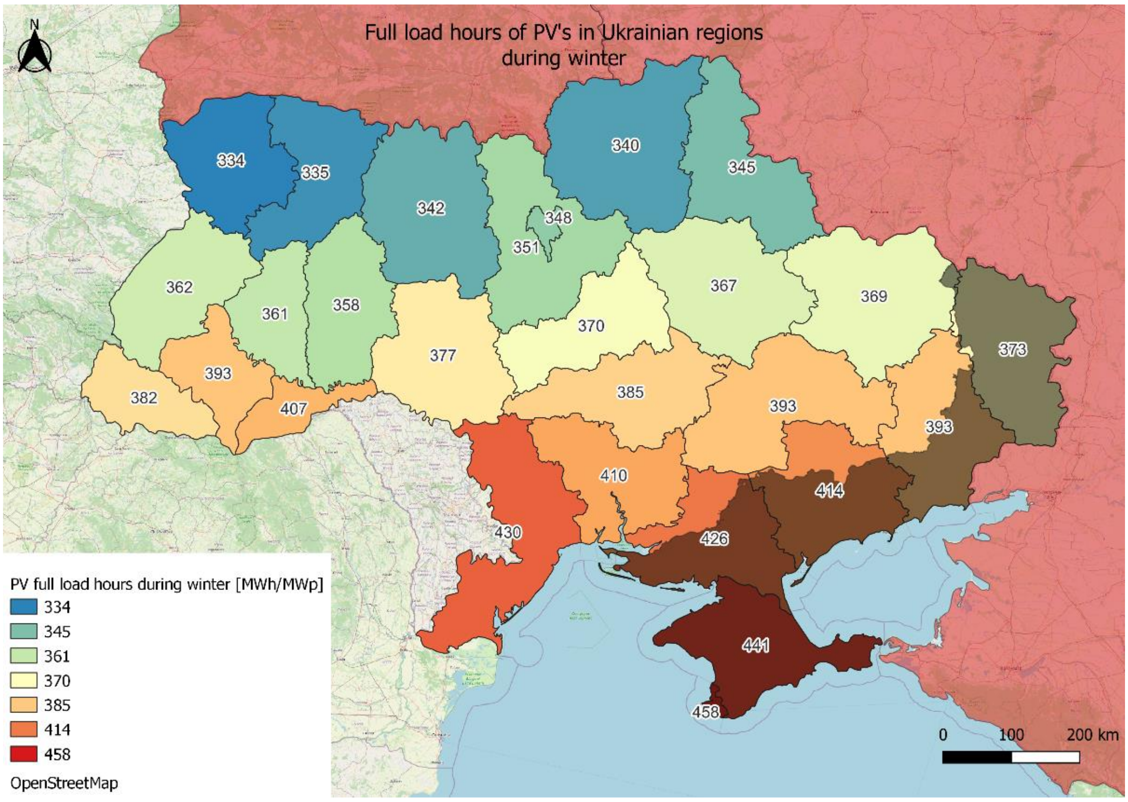


Figure 10 : Expected wintertime PV generation (MWh per MW installed capacity) in different regions of Ukraine. A wintertime production of 350 MWh/MW corresponds to app. 30 % of the annual production and a capacity factor of 8%. The maps are set up calculating the generalized power generation from photovoltaics, in the different Ukrainian regions, Global Solar Atlas covering the period between 1994-2018 was used.

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

The levelized cost of electricity generation over two winters (emergency perspective) amount to approximately:

- 3000 €/MWh for PV residential rooftop
- 6000 €/MWh for PV comm. & industrial - with battery
- 2700 €/MWh for PV comm. & industrial
- 2400 €/MWh for PV Utility-scale
- 4000 €/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, which spans a minimum of 30 years, barring any unforeseen events:

- 75 €/MWh for PV residential rooftop
- 135 €/MWh for PV comm. & industrial - with battery
- 70 €/MWh for PV comm. & industrial
- 70 €/MWh for PV Utility-scale
- 80 €/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 analyzes, except for Wind and hydro. Combining with batteries makes the LCOE approximately double the LCOE.

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 favor distributed solar PV installations. These installations, located near demand centers, 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 includes inspection and calculation to conclude if the construction of the roof is appropriate for installing the modules, which 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 is achieved by signing electricity purchase and sale agreements under the self-generation mechanism, 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 in 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 typical less than 10 weeks, but for the transformer and inverters in some cases, it can extend up to two 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 parks, one effective approach is to commence with projects that have already undergone exhaustive due diligence.

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

In general, PV modules in stock on the marked in 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 in 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 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 can be installed in less than a week and commercial / public 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 in same extent as for large wind power.

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

Based on the previous experience with erecting about 6.6 GW of PV capacity it is expected that skilled staff is 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 installations in Ukraine.

In tender specifications, it is highly recommended to stipulate the inclusion of a mandatory service contract for at least the initial two 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 in some extent of 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 underscores that the central regions of Ukraine, which face a lower risk of Russian artillery or missile attacks, continue to offer reasonable electricity generation potential, even during the winter season.

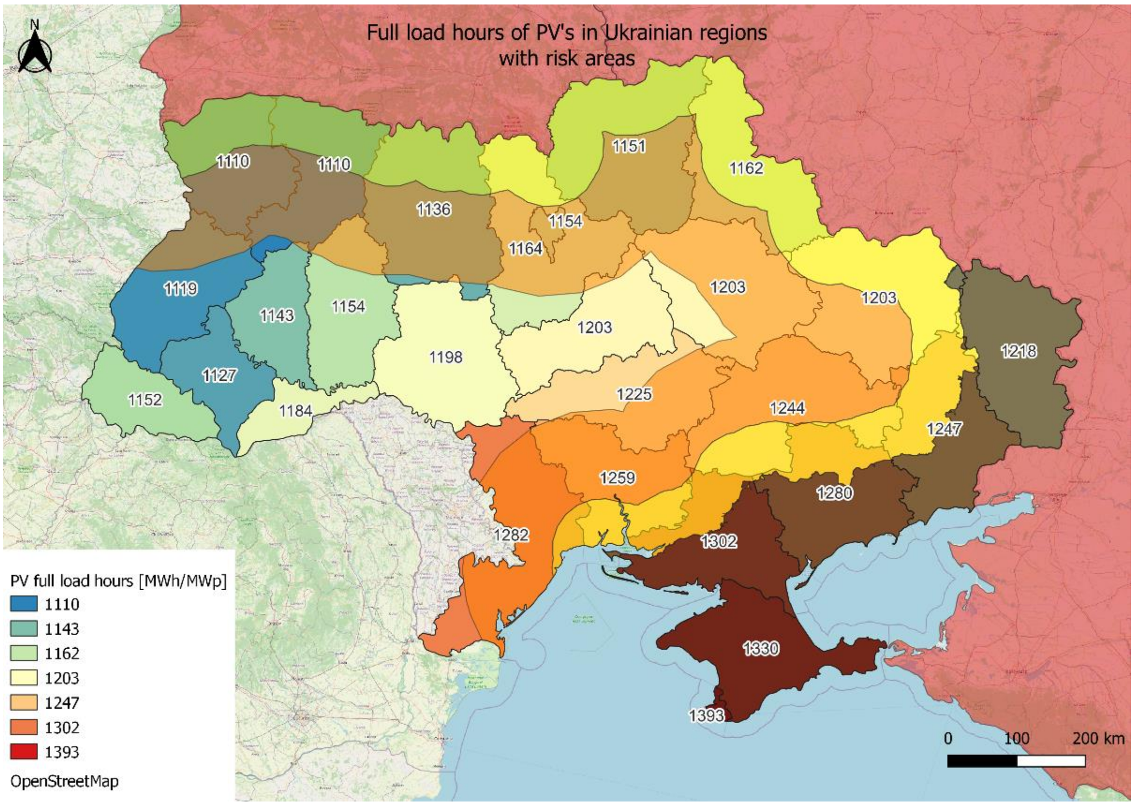


Figure 11 Expected annual PV generation (MWh per MW installed capacity) in different regions of Ukraine. An annual production of 1200 MWh/MW corresponds to a capacity factor of 14%. Buffer zones of 100km and 280km was applied from Russian controlled areas and Belarus, accounting for the longest range 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 1994-2018 was used.

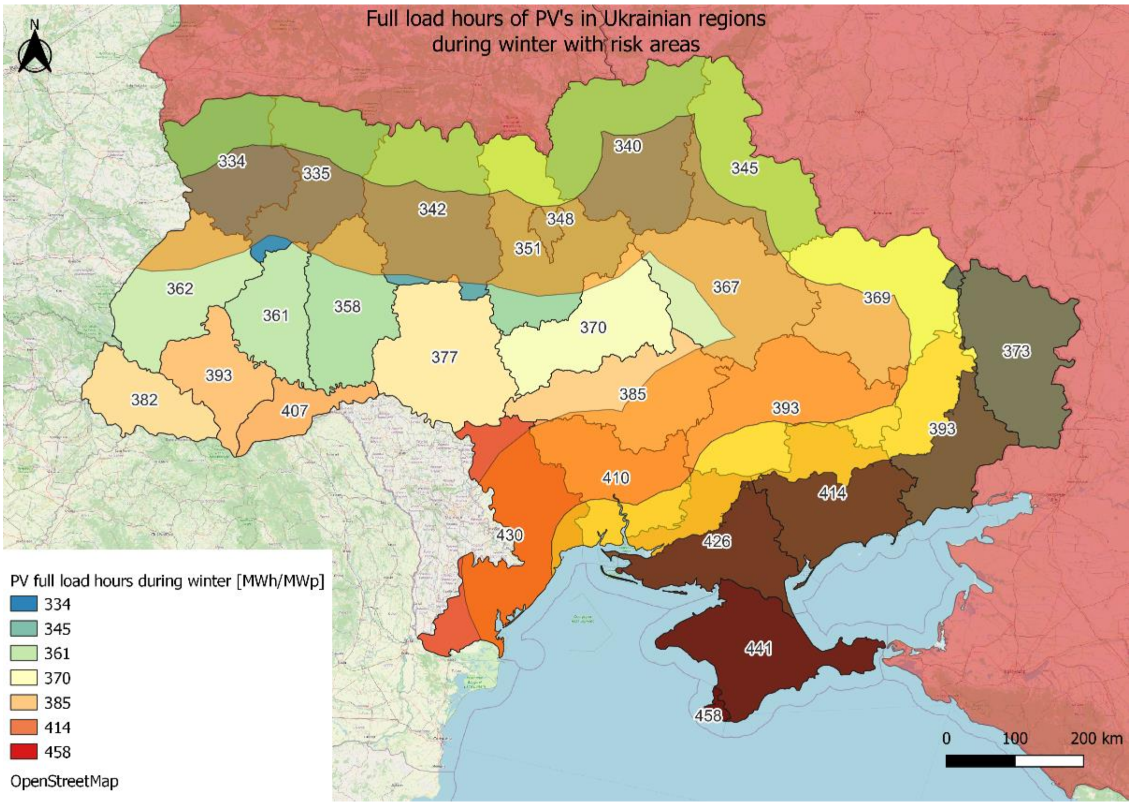


Figure 12 Expected wintertime PV generation (MWh per MW installed capacity) in different regions of Ukraine. And wintertime production of 350 MWh/MW corresponds to app. 30 % of the production and a capacity factor of 8%. Buffer zones of 100km and 280km was applied from Russian controlled areas and Belarus, 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 1994-2018 was used.

P14: Risk associated with fuel supply (R)

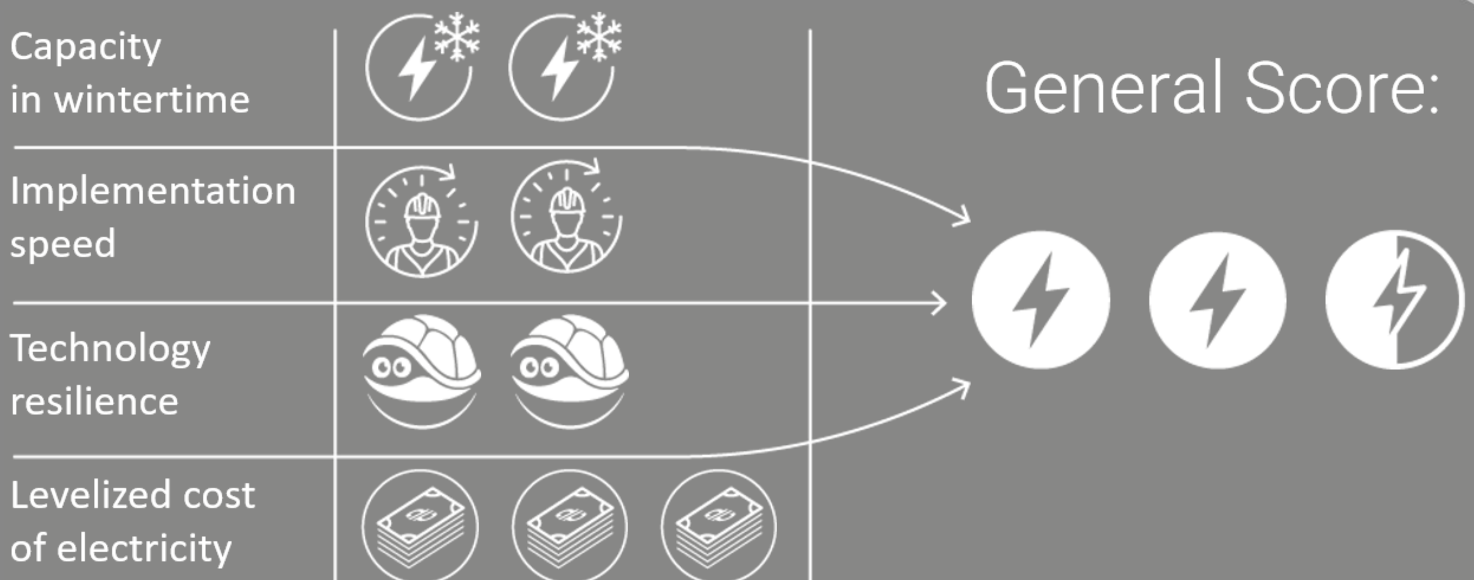
Not relevant

1.1.13 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, aligning with the United Nations Development Programme on Energy service companies (UNDP ESCO) initiative's objectives aimed at enabling such investments.

Onshore Wind



ONSHORE WIND

Criteria evaluation	3.a. Wind onshore parks (>20MW)	3.a. Used wind onshore parks (>20MW)	3.a. Wind onshore cluster (4,2-20MW)	3.c. Wind domestic turbines (<100kW)
Capacity in wintertime	WW	WW	WW	WW
Implementation speed	Q	QQ	Q	QQQ
Technology resilience	RR	RR	RR	RRR
Levelized cost of electricity	CCC	CCC	CCC	C
General score (1-3)	2.0	2.3	2.0	2.3

This chapter covers four different types of onshore wind technologies:

- Large-scale onshore wind farm (20-100 MW)
- Cluster of onshore wind turbines (5-20 MW)
- Used wind turbines for a large-scale onshore wind farm (20-100 MW)
- Domestic wind turbines

The three first 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.

Domestic wind turbines on the other hand are in 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.

1.1.14 Onshore wind turbines (MW scale)

Brief technology description

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

The typical large 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.

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 13.

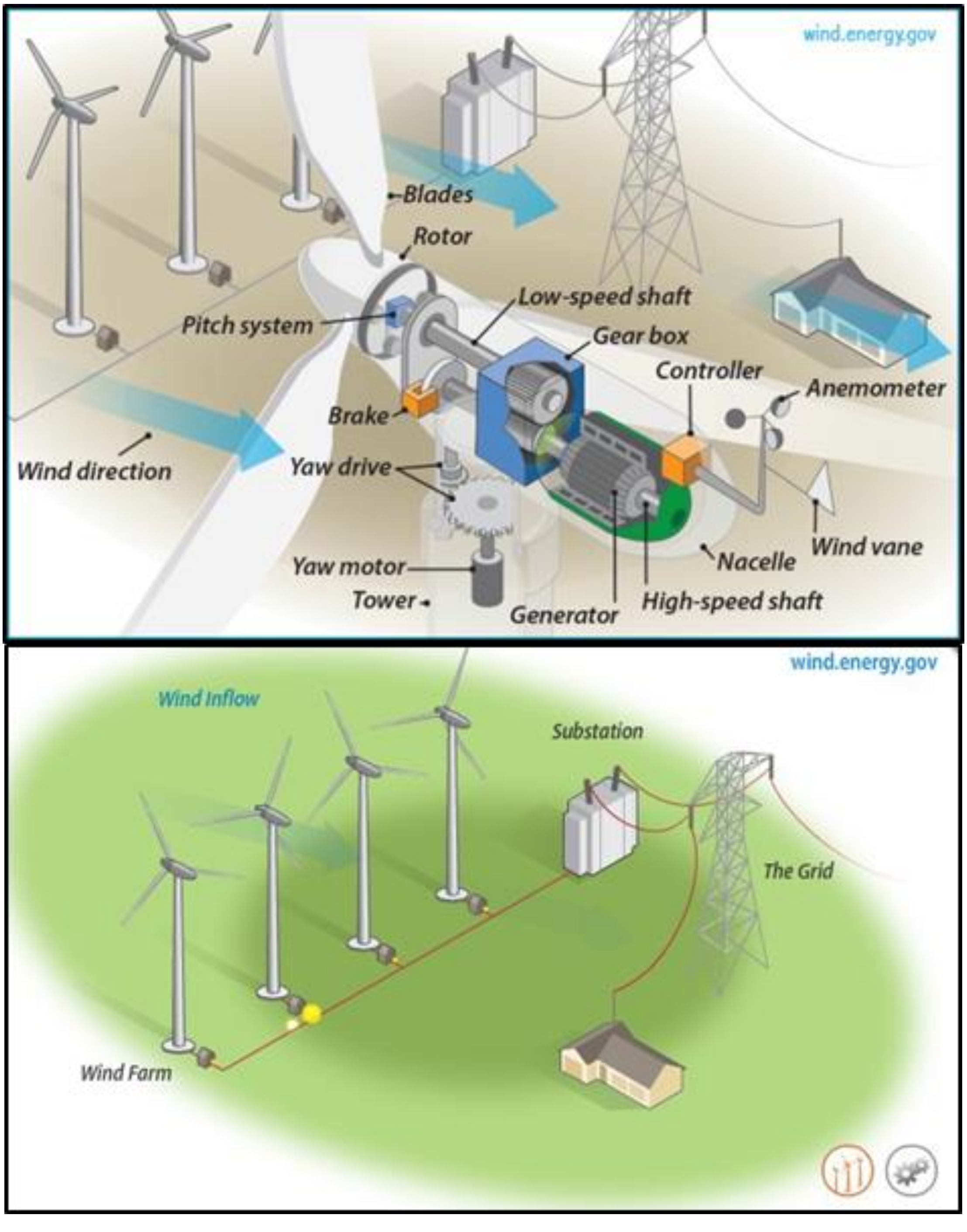


Figure 13 General wind turbine technology and electrical system

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 14 Four Vestas 3 MW wind turbines

Figure 15Figure 15 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[10]. More details on

---

[10] 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: https://www.lmwindpower.com/en/stories-and-press/stories/learn-about-wind/what-is-a-wind-class the calculation methodology can be found in Appendix E.

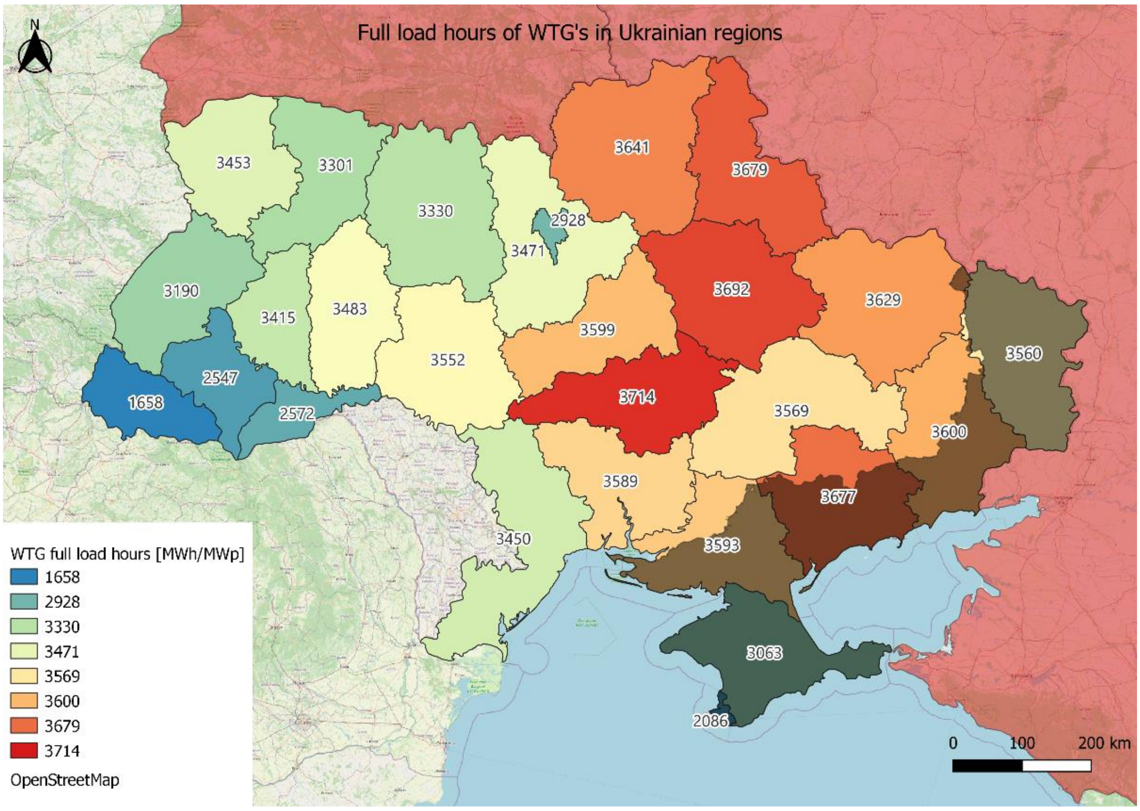


Figure 15: Wind resource chart, expected annual wind turbine generation (MWh per MW installed capacity) in different regions of Ukraine. An annual production of 3500 MWh/MW corresponds to a capacity factor of 40%.

Criteria evaluation

Large-scale onshore wind farm (20-100 MW)

Criteria evaluation	3.a. Wind onshore parks (>20MW)
Capacity in wintertime	WW
Implementation speed	Q
Technology resilience	RR
Levelized cost of electricity	CCC
General score (1-3)	2.0

Table 13 Wind Power - criteria evaluation matrix

Winter impact, production at wintertime(W)

Large-scale onshore wind farm will be able to provide a significant contribution to the Ukrainian power system during wintertime. Obviously, the production depends on the weather patterns and there will 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.

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 two years) and feasibility studies and siting analyzes (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 a large 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)

Large-scale 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)

Criteria evaluation	3.a. Wind onshore cluster (4,2-20MW)
Capacity in wintertime	WW
Implementation speed	Q
Technology resilience	RR
Levelized cost of electricity	CCC
General score (1-3)	2.0

Table 14 Wind Power - criteria evaluation matrix

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 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 two years) and feasibility studies and siting analyzes (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 large 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.

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.

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 fairly a cost-efficient option, despite its initial capital investment.

Used wind turbines for a large-scale onshore wind farm (20-100 MW)

Criteria evaluation	3.a. Used wind onshore parks (>20MW)
Capacity in wintertime	WW
Implementation speed	QQ
Technology resilience	RR
Levelized cost of electricity	CCC
General score (1-3)	2.3

Table 15: Wind Power - criteria evaluation matrix

Winter impact (production at wintertime)

Used wind turbines – typically 8-10 years old and with a capacity of 3 MW – applied in a large-scale (20-100 MW) wind farm 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 siting analyzes (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.

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.

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 cases 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.

Parameter evaluation

Parameter evaluation	3.a. Wind onshore parks (>20MW)	3.a. Used wind onshore parks (>20MW)	3.a. Wind onshore cluster (4,2-20MW)
P1-Electricity production at wintertime	50%	50%	50%
P2-Levelized Cost of Electricity (LCOE) short lifetime, winter production	881	622	1010
P3-Levelized Cost of Electricity (LCOE) over lifetime	41	41	46
P4-Distributed generation	>20 MW	>20 MW	4,2-20 MW
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 potential	Medium potential	Medium potential
P14-Risk associated with fuel supply	Low risk	Low risk	Low risk

Table 16: Wind Power - parameters evaluation matrix for onshore (MW scale)

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

P1: Electricity production at 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.

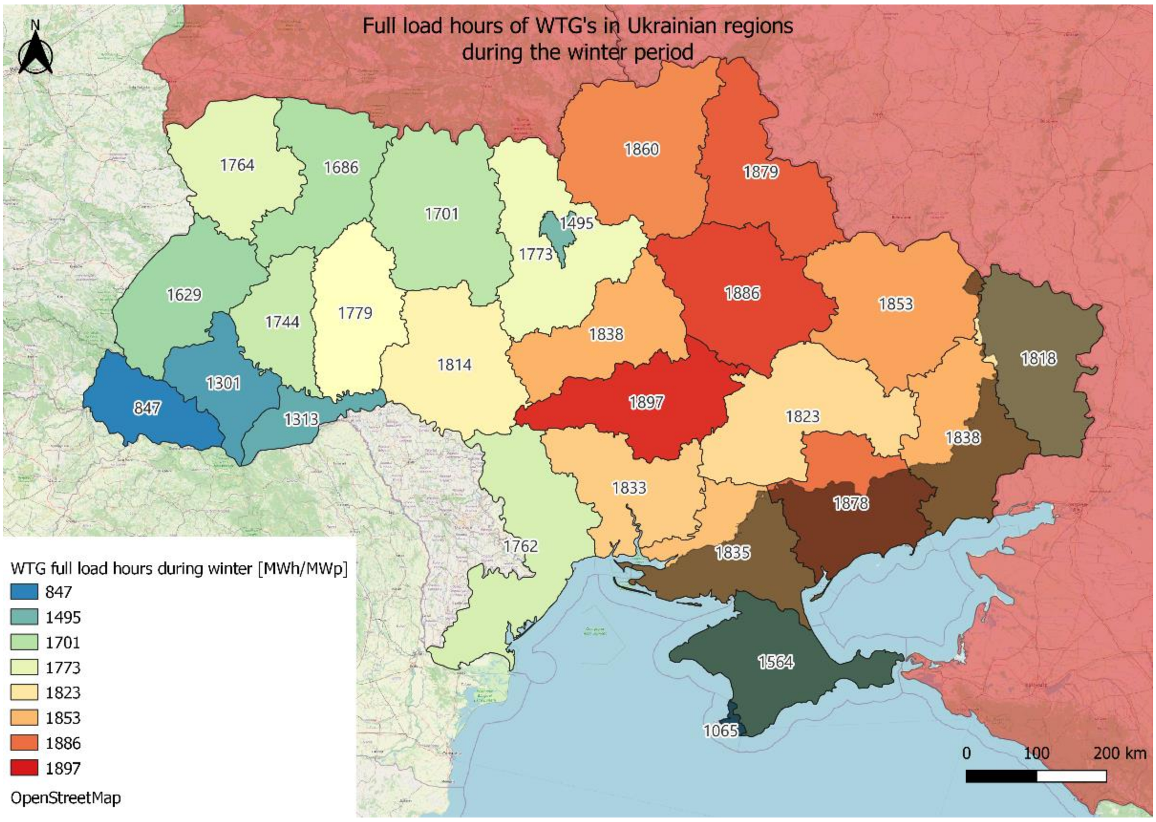


Figure 16: Expected Wind turbine generation (MWh per MW installed capacity) in different regions of Ukraine during wintertime (which in this context is defined as October-March, 4374 hours in total).

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

The levelized cost of electricity generation over two winters (emergency perspective) amount to about 880 €/MWh for a large wind farm (20-100 MW) and slightly higher, about 940 €/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 €/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)

Large onshore wind farms (20-100 MW) demonstrate low LCOEs of around 40 €/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 make 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 analyzes 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 measurement may take about a 1 year to be sufficiently reliable. However, the Ukrainian Wind Energy Association expect that by February 2024 an electronic wind atlas will be ready covering on 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 large 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 state of war. The 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 to a specific project, 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 case up to two 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 six months to two 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, 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 project's delivery depends on many factors such as size, complexity, access to 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 two 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 a 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 large scale farm of up to 100 MW, in itself has limited 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 the distance.

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

Less than one year. If experienced construction companies are present, a large-scale 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 with erecting about 1.17 GW of wind capacity it is expected that skilled staff is 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 in 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 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 are 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 lack of training programs or migration of qualified workers. Based on the previous experience with erecting about 1.7 GW of wind capacity it is expected that skilled staff is 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 exception of the central and southeastern part, 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 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.

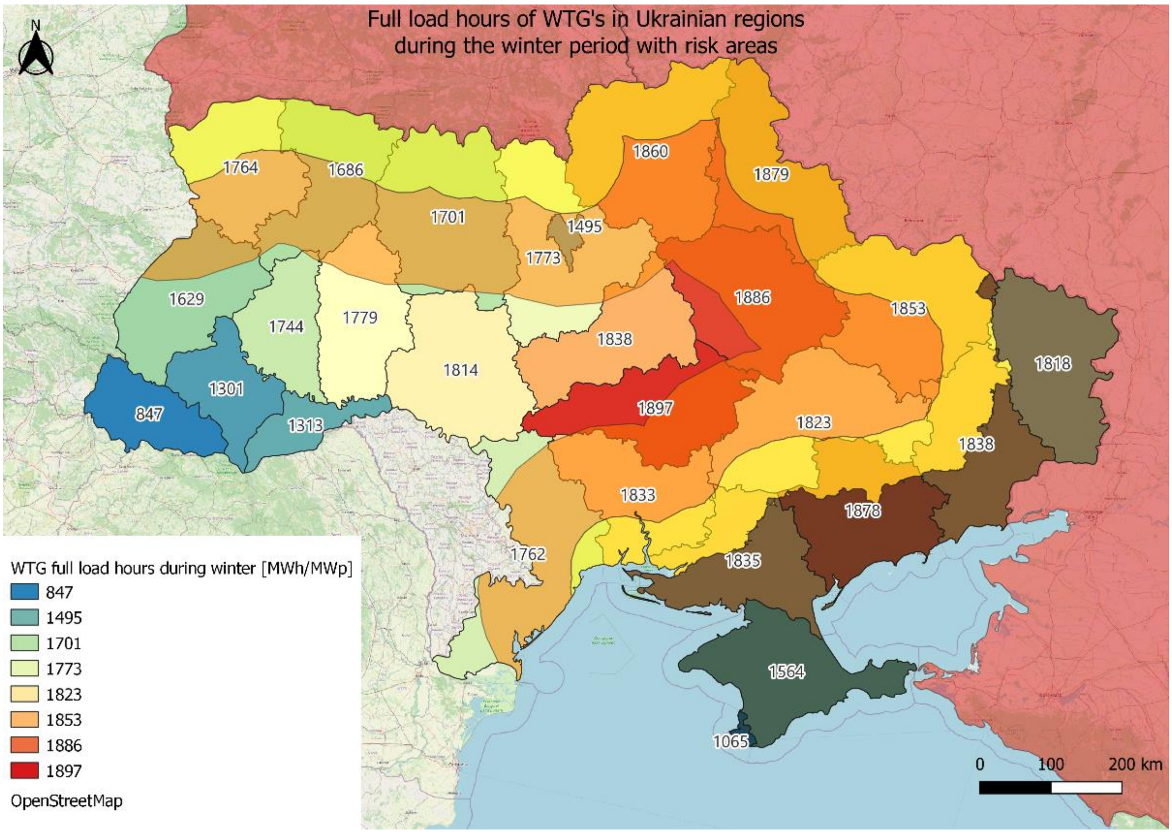


Figure 17: Expected wind turbine generation (MWh per MW installed capacity) in different regions of Ukraine during wintertime (which in this context is defined as October-March, 4374 hours in total) along with an indication of the range of Russian artillery and close-range ballistic missiles.

P14: Risk associated with fuel supply (R)

Not a relevant risk for wind turbines.

Additional technology-specific insights from the interviews

Foreign investors such as IBRD (The International Bank for Reconstruction and Development (IBRD), 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 creating a so-called Master Plan or General Plan and in developing the projects, along with an Insurance Fund that would cover military risks.

Foreign renewable energy developers point out that it could ensure a fast development if the state could expropriate land and grant a building permit for the wind turbine parks.

The Ukrainian Wind Energy Association asserts that the policy of the National Commission for State Regulation of Energy and Public Utilities (NCSREPU), especially regarding responsibility for imbalances, is seriously hindering the development of not only the wind sector but also solar energy.

1.1.15 Domestic wind turbines

Brief technology description

Domestic wind turbines have installed capacity of 1-100 kW, with a rotor swept area smaller than or equal to 200 m2, generating electricity at a voltage below 1 000 V AC or 1 500 V DC

Domestic wind turbines are commonly cited close to buildings in residential areas. By Ukrainian law it is allowed to install domestic wind turbines with a capacity of up to 50 kW in private households. For the proper placement of domestic wind turbines, it is important to maintain a suitable distance, approximately 20 meters from the nearest building. Small wind turbines can produce noticeable noise owing to their rapid rotations and high operating speed.

The capacity factor of small wind turbines varies a lot depending on the local conditions. The wind turbines are often located close to buildings and trees, which will reduce the annual production from the wind turbines because of turbulence from buildings and trees. The specific output power will, as for the larger turbines, have an impact on the capacity factor and so have the relative low hub height. Domestic wind turbines can use generated electricity for in-house consumption, in addition to exporting power to the utility grid.

Figure 18 ANTARIS 2.5 kW domestic wind turbines

Criteria evaluation

Criteria evaluation	3.c. Wind domestic turbines (<100kW)
Capacity in wintertime	WW
Implementation speed	QQQ
Technology resilience	RRR
Levelized cost of electricity	C
General score (1-3)	2.3

Table 17: Domestic Wind Power - criteria evaluation matrix

Winter impact (production at wintertime)

Domestic 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 analyzed data for Ukraine 51% of the full load hours occurred during the cold period (see Figure 17 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, 4374 hours in total) along with an indication of the range of Russian artillery and close-range ballistic missiles. 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 domestic wind turbine in Ukraine.

Planning and building a domestic wind turbine in Ukraine involve 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 two days. Skilled staff from a specialized company are required for the installation and commissioning phases.

Resilience

A domestic 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 domestic wind turbine amounts to approximately 2600 €/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 domestic wind turbines, is considered medium heigh compared to the alternatives investigated in this technology catalogue.

Parameter evaluation

In summary, domestic wind turbines in Ukraine offer steady electricity generation, with advantages in distribution, regulatory processes. Their smaller size may also enhance resilience to potential threats. The LCOE over two winters is around 2600 €/MWh, which is more than double the cost pr MWh as larger onshore wind turbines but comparable to residential rooftop PVs. Over the lifetime, domestic wind turbines demonstrate a LCOE of around 170 €/MWh.

Parameter evaluation	3.c. Wind domestic turbines (<100kW)
P1-Electricity production at wintertime	50%
P2-Levelized Cost of Electricity (LCOE) short life-time, winter production	2637
P3-Levelized Cost of Electricity (LCOE) over life-time	167
P4-Distributed generation	0,1 MW
P5-Regulation requirement in the project devel-opment 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 infrastruc-ture	Easy
P12-Requirements for skilled staff for operation and maintenance and for special spare parts	Low
P13-Possibility for camouflage and sheltering	High potential
P14-Risk associated with fuel supply	Low risk

Table 18: Wind Power - parameters evaluation matrix for onshore (kW scale)

P1: Electricity production at wintertime (W)

According to analyzed data for Ukraine 51% of the full load hours occurred during the cold period (see Figure 16). 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) amount to about 2600 €/MWh for a domestic 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)

Domestic wind turbines demonstrate medium LCOEs of around 170 €/MWh over the lifetime of the turbines, which is minimum 20 years in absence of unexpected events.

P4: Distributed generation (R)

Domestic 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 domestic 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 domestic 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 domestic 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 domestic 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 at 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 two days.

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

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

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

Domestic wind turbines can, in the same way as larger wind turbines, be used for down-regulation, 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 domestic 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.

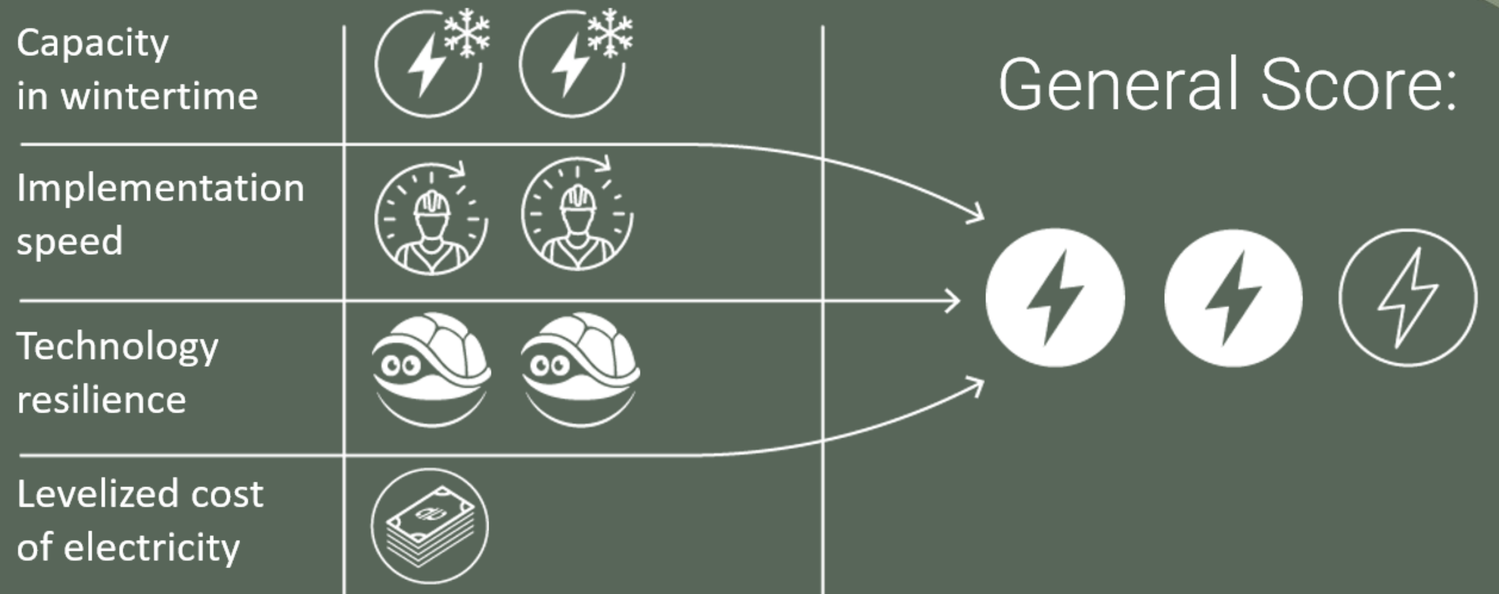
P13: Possibility for camouflage and sheltering (R)

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 domestic 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.

Batteries



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

BATTERIES

1.1.16 Brief technology description

With increasing shares of renewable energy in power systems, the role of electricity storage grows in importance. Among all technologies, electrochemical storage (batteries) has experienced notable cost declines in the past years. This is especially true for certain battery types; this catalogue considers the Li-Ion type, which is in operation in many different grid applications around the world. The potential applications of batteries in electricity systems are very broad, ranging from supporting weak distribution grids, to the provision of bulk energy services or off-grid solutions.

To understand the services batteries can provide to the grid, Rocky Mountain Institute performed a meta-study [2] 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 19). 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).

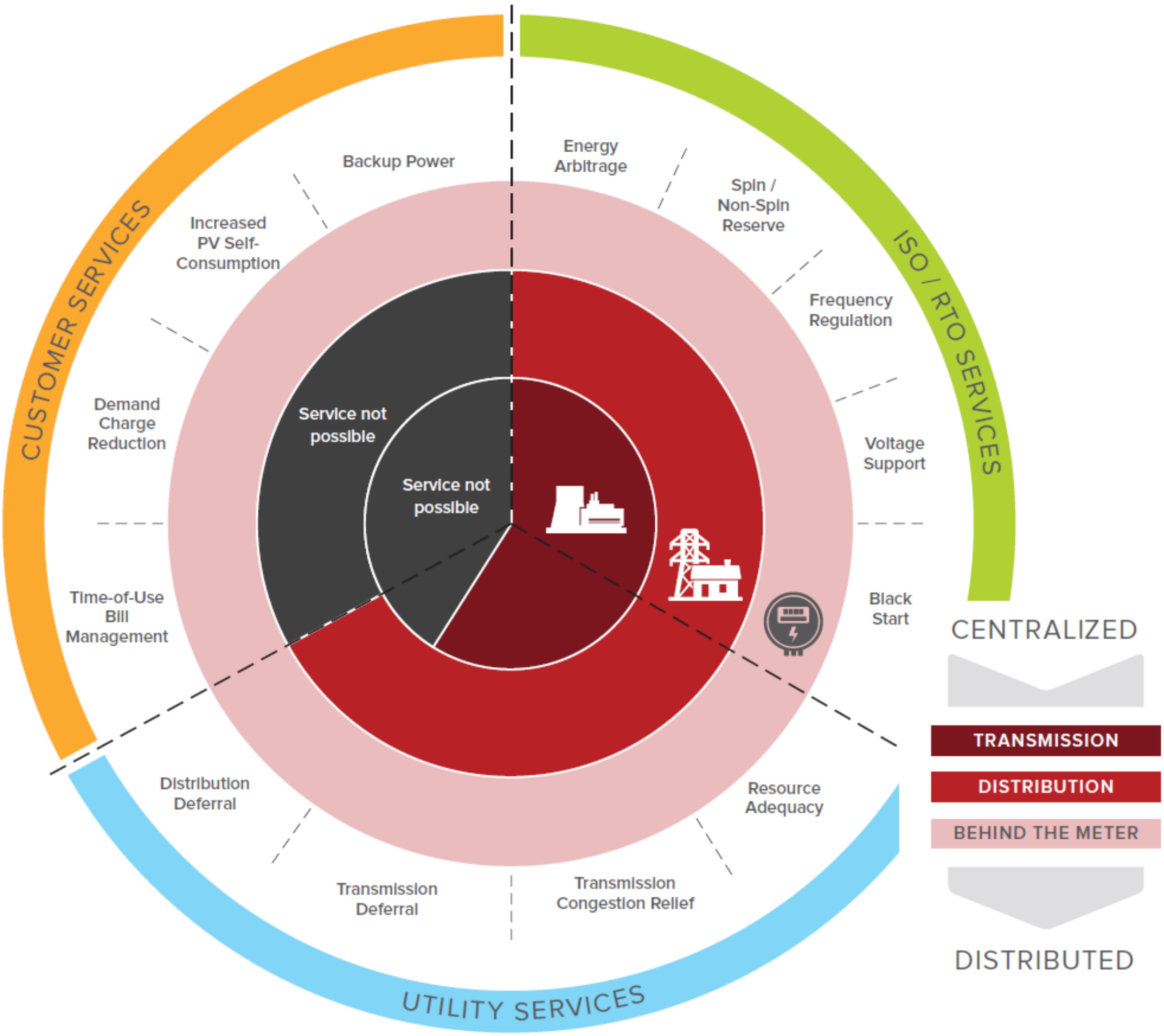


Figure 19: Services batteries can provide to different stakeholder groups [2]

This technology description focuses on batteries for provision of bulk energy services (e.g., grid-scale batteries) and customer energy management services (e.g., community batteries), 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, power reliability and quality.

Lithium-ion batteries (LIB) have however completely dominated the market for grid scale energy storage solutions in the last years and appear to be the dominating battery solution. For this reason, this chapter focuses on LIB. 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 come 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.

1.1.17 Grid-scale batteries

Brief technology description

A schematic overview of a battery system and its grid connection can be seen in Figure 20. A Thermal Management System (TMS) controls the temperature in the battery packs to prevent overheating and thermal runaway. The Energy Management System regulates the 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.

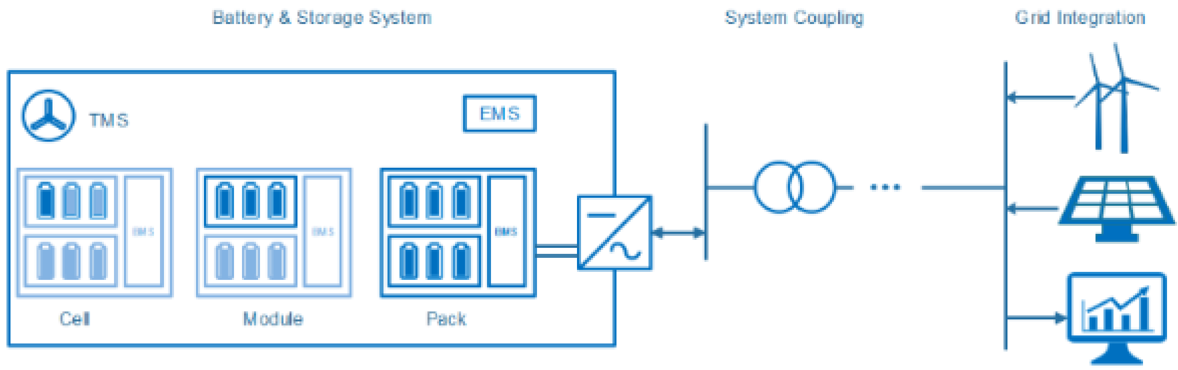


Figure 20: Schematic illustration of a grid-scale battery storage system

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 is discharged in 20 minutes, 1 hour and 2 hours then it has C-rates of 3C, C and C/2 respectively. Operations at higher C-rates than specified in the battery pack are possible but would lead to a faster degradation of the cell materials [3]. 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 [4]. 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 better measured by the total number of cycles undergone over the lifetime. Nowadays, a Li-Ion battery typically endures around 10,000 full charge/discharge cycles.

1.1.18 Community batteries

Brief technology description

Battery energy storage systems can have manifold applications and thus can be installed at different scales and voltage levels (see Figure 19). BESS architecture is ultimately shared across use types, with minor differences depending on the single applications. In off-grid and micro-grid (e.g., community batteries) contexts, grid connection costs are reduced totally or partially.

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 are related to retail tariff savings, peak tariff reduction, reliability, and quality of supply [5]. 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 requirements enforced by the regulation, but also materialize in remunerated system services.

Biogas

BIOGAS PLANT

The biogas plant is only included as a technology which produce fuel to the gas engine, fueled by biogas, solely supplyed by a greenfield project biogas plant. In this secition only a brief technology decribtion of the biogas plant is included. The evaluation of the biogas power produced by the gas engine is made in the section.

Brief technology description

Biogas produced by anaerobic digestion is a mixture of several gases (syngas). The most important part of the biogas is methane. Biogas has a caloric value between 23.3 – 35.9 MJ/m3, depending on the methane content. The percentage of volume of methane in biogas varies between 50 to 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 [6], [7]

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 which 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^{o}C (mesophilic) or 55 – 58^{o}C (thermophilic). Mesophilic gives hydraulic retention time (HRT) between 25 – 35 days and thermophilic 15 – 25 days [6]

Examples of expected feedstocks of biogas production in Ukraine are manure, 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).

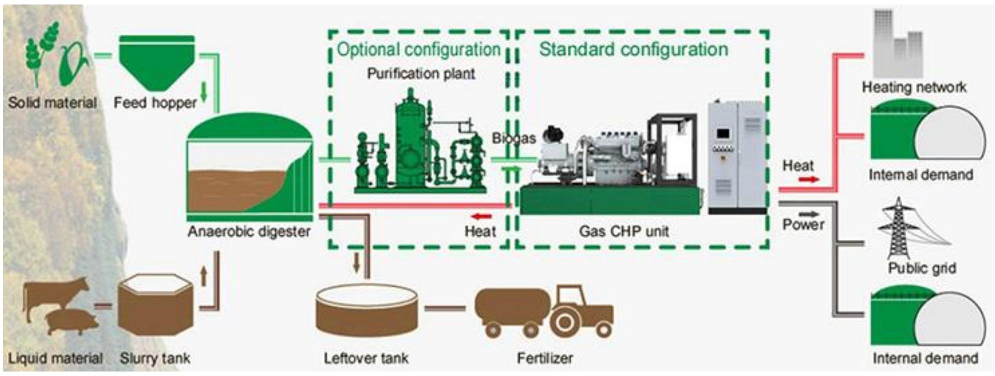


Figure 21: Schematic diagram for a biogas CHP system [8]

Coal Power Plants, Lifetime Extension

Capacity in wintertime

Implementation speed

Technology resilience

Levelized cost of electricity

General Score:

COAL POWER PLANTS, LIFETIME EXTENSION (REPLACEMENT OF PLANT'S EQUIPMENT)

Brief technology description

When a coal power plant has been in operation for 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 'Life Time Extension' (LTE) is done with the purpose of restoring the plant to come close to its original conditions 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 [9]

It may be convenient to carry out all necessary works in one campaign, to reduce the overall down time. For this case it is assumed that all work is done in one campaign. It is expected that the original plant complies 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.

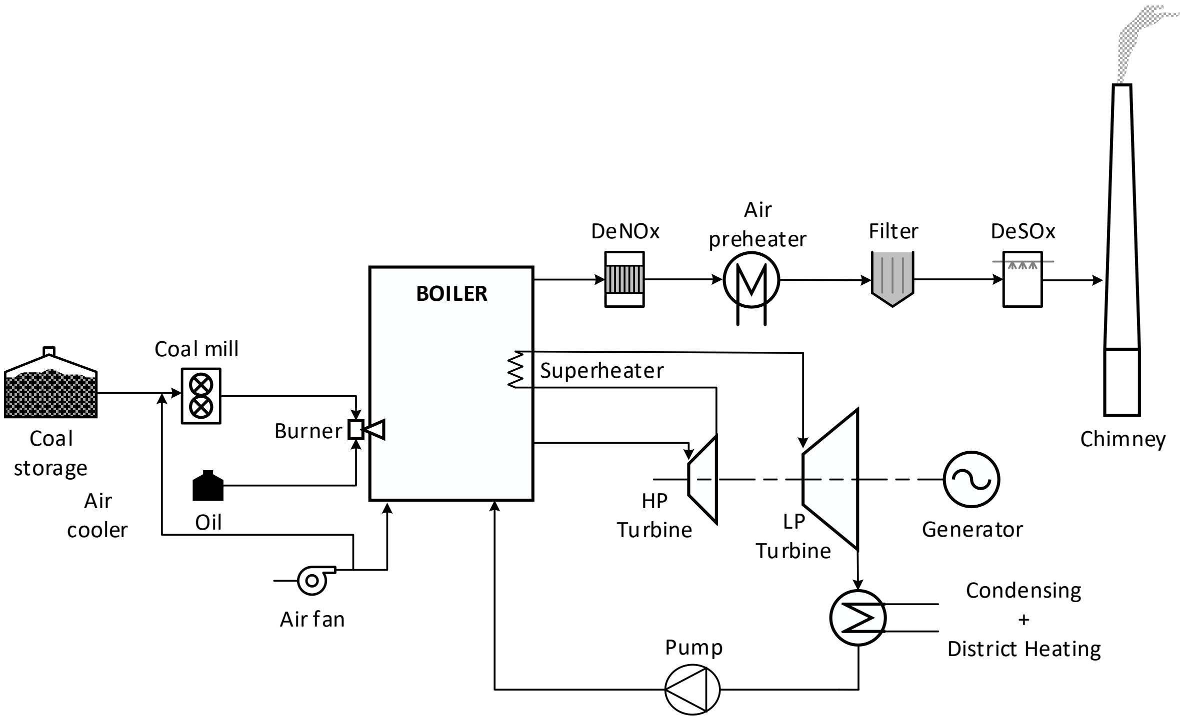


Figure 22: Sketch of the main elements of a large coal fired CHP plant

In connection with the LTE the plant will be out of operation for a period, typically 6-9 months. However, depending widely on the actual scope, the distribution of works and costs involved with a LTE of and existing coal fired plant could typically be as follows [9]:

- Revision of electrical systems
- Instrumentation and control systems replacement
- Pulverizers 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

The basis for deciding which works to include in the LTE is an understanding of the plant's condition, which can be obtained using diagnostic systems and making a detailed remaining life assessment [10]

Biomass Cogeneration Technologies

BIOMASS COGENERATION TECHNOLOGIES

Brief technology description

This chapter focuses on solid biomass for combustion destinated 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; saw-dust and nut shells may be relevant as energy source, while different fuels set different technical requirements for the plant, these differences will not be addressed.

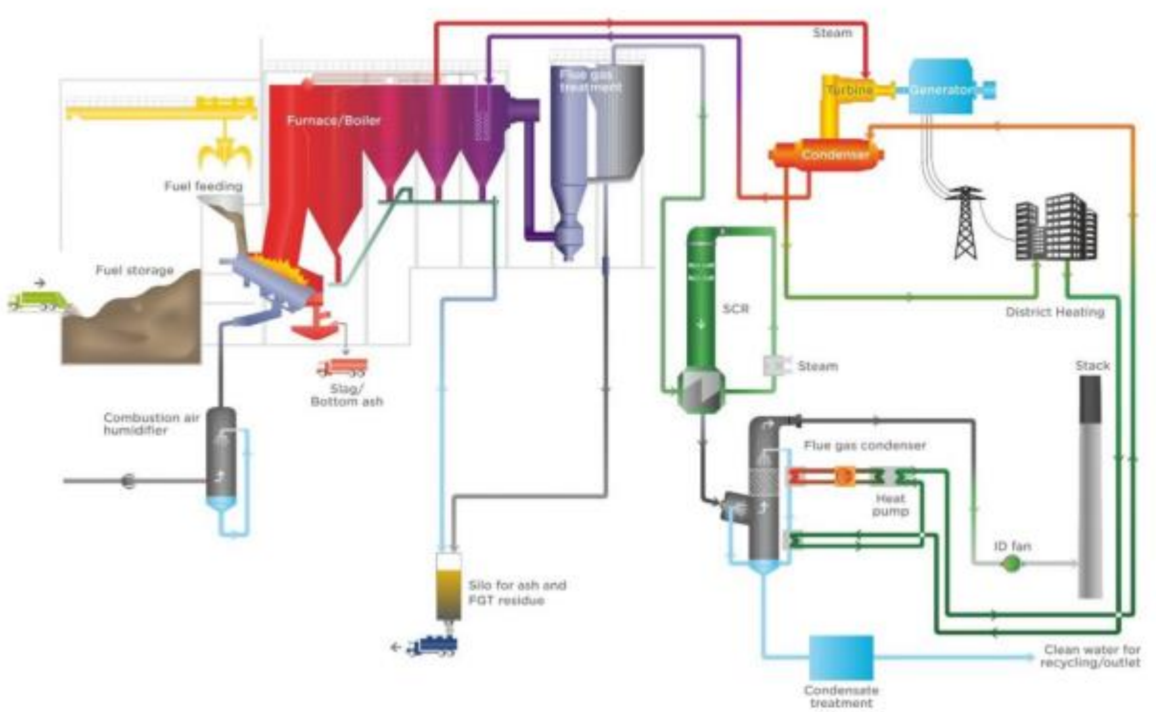


Figure 23: Main systems of a CHP facility, example waste to energy CHP facility[Technology Data - Energy Plants for Electricity and District heating generation, 2016, Danish Energy Agency]

The main systems are presented in Figure 2323. The main systems of a biomass fired 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.

Energy conversion in CHP of biomass is the combustion. The electricity production requires operating temperatures higher than if only producing heat. CHP production from biomass has been used in an increasing scale for many years utilizing different technologies e.g. in Denmark. The typical implementation is combustion in a biomass boiler feeding a steam turbine. The energy output from the boiler is (high pressure) steam to be expanded through a turbine. 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. The extraction unit can run both in backpressure and condensing mode as well as every combination in between.

Application of flue gas condensation for further energy recovery is customary at biomass fired boilers using feedstock with high moisture content, e.g., wood chip, 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. The flue gas condensation may raise the heating efficiency with 5-10%.

1.1.19 Organic Rankine cycle plants

Brief technology description

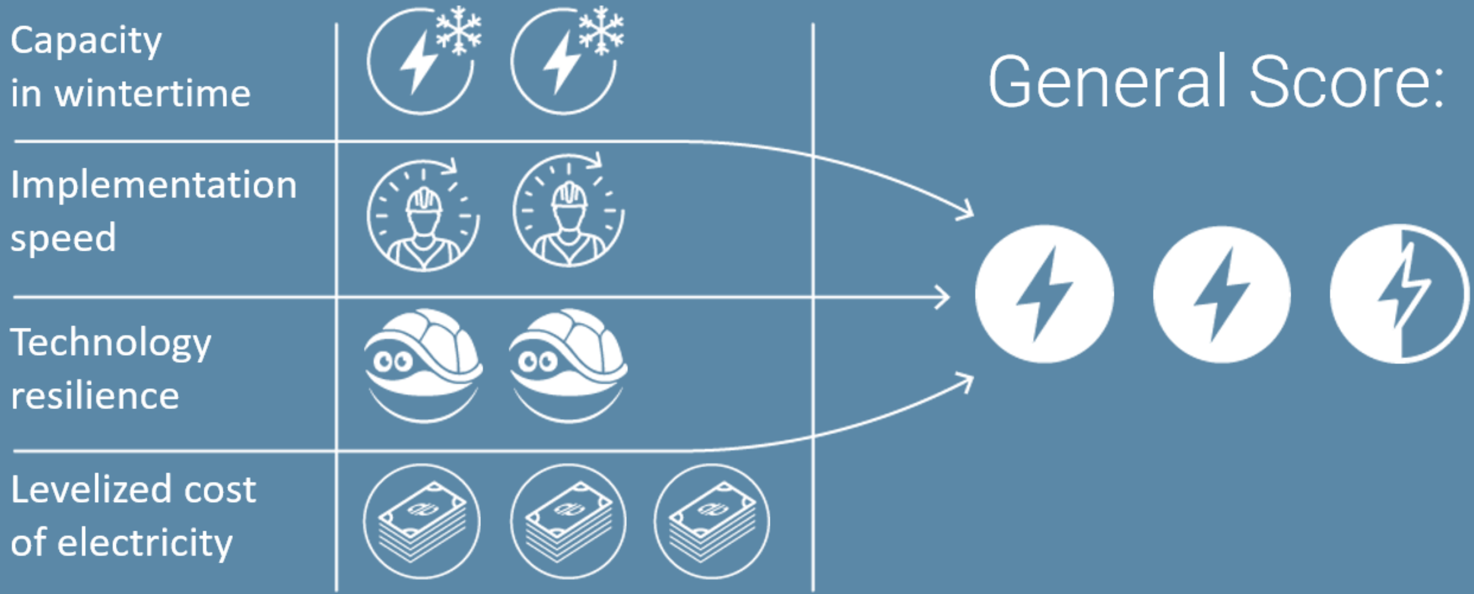
An alternative type of CHP plant is the organic Rankine cycle plants (ORC plants). In this the (biomass-) boiler is used for heating (no evaporation) thermal oil. This heated oil transfers the heat to an ORC plant which is similar to a steam cycle, but it uses a refrigerant instead of water as working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

The reason for an interest in ORC plants is that such equipment is delivered in standardized complete modules at an attractive price and in combination with 'a boiler' that only is used for heating oil, the investment is relatively modest. 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 – this makes them less flexible but cheap. This may make it financially attractive to build 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 media i.e., a refrigerant or silicone oil (an organic compound that can burn but does not explode) with thermodynamic properties that makes it more adequate than water for low temperature power generation.

Common technology description for biomass and WtE is found in chapter "Introduction to Waste and Biomass Plants". Also, flue gas condensation, combustion air humidification, fuels and an improved energy model for technology data are described there.

Run-of-river Hydropower



RUN-OF-RIVER HYDROPOWER

Brief technology description

In a hydropower plant, the potential energy is converted into rotational kinetic energy, which spins the blades of a turbine connected to a generator. Figure 2324 shows a run of river hydropower plant.

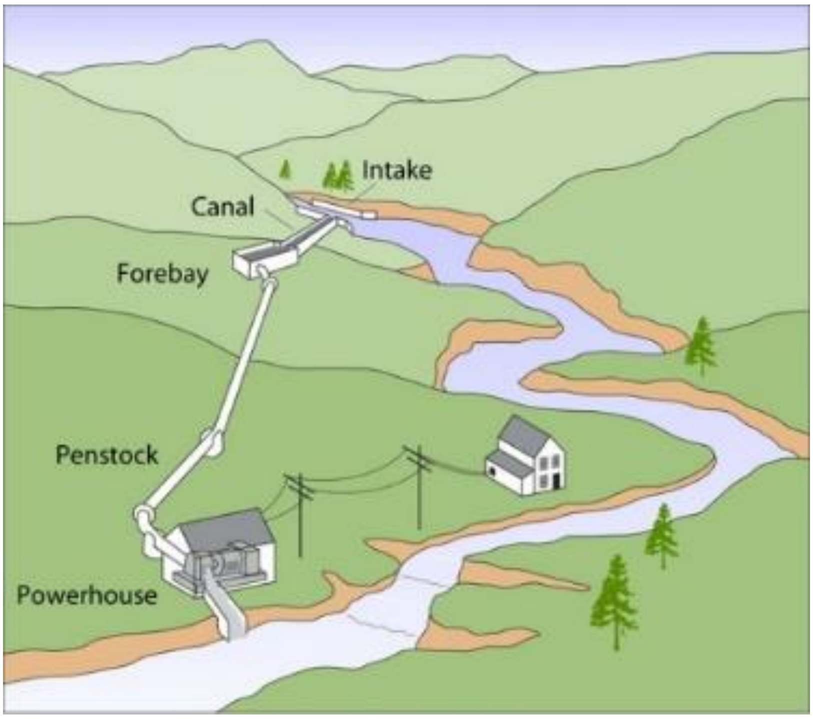


Figure 24:Run-of-river hydropower plants

The capacity factor achieved by hydropower projects needs to be looked at somewhat differently than for other renewable 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 figures), with a significant standard deviation across geography.

REFERENCES

[1] "Nag, 'Power plant engineering', 2009 - Google Scholar." Accessed: Oct. 16, 2023. [Online]. Available: https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=Nag%2C+%E2%80%9CPower+plant+engineering%E2%80%9D%2C+2009&btnG=

[2] G. Fitzgerald, J. Mandel, J. Morris, and H. Touati, "The Economics of Battery Energy Storage - How Multi-use, Customer-sited Batteries Deliver the Most Services

and Value to Customers and the Grid," 2015.

[3] K. Takei *et al.*, "Cycle life estimation of lithium secondary battery by extrapolation method and accelerated aging test," in *Journal of Power Sources*, 2001. doi: 10.1016/S0378-7753(01)00646-2.

[4] Y. Nishi, "Lithium ion secondary batteries; Past 10 years and the future," *J Power Sources*, vol. 100, no. 1–2, 2001, doi: 10.1016/S0378-7753(01)00887-4.

[5] H. C. Hesse, M. Schimpe, D. Kucevic, and A. Jossen, "Lithium-ion battery storage for the grid - A review of stationary battery storage system design tailored for applications in modern power grids," *Energies*, vol. 10, no. 12. 2017. doi: 10.3390/en10122107.

[6] "Biogas Technology and Biomass, Renewables Academy," Berlin, Germany.

[7] "Jorgensen, 2009. Biogas – green energy, Faculty... - Google Scholar." Accessed: Oct. 16, 2023. [Online]. Available: https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=1.%09Jorgensen%2C+2009.+Biogas+%E2%80%93+green+energy%2C+Faculty+of+Agricultural+Sciences%2C+Aarhus+University%2C+2nd+edition%2C+Denmark&btnG=

[8] "Danish Climate Strategy," Copenhagen, Denmark, 2003.

[9] DECC, "Electricity Generation Costs (December 2013)," 2013.

[10] R. M. Ambrosini, "Life extension of coal-fired power plants.," 2005.

[11] H. J. , and P. Alderliesten. Veringa, "Advanced techniques for generation of energy from biomass and waste," 2004.

[12] G. Simbolotti, "Biomass for power generation and CHP," 2007.

APPENDIX A: METHODOLOGY

Description of the new 14 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.

1.1.20 P1: Electricity production at wintertime

This technology catalogue is to high extend concerned about the ability to generate electricity during wintertime. Ukraine has higher electricity demand, and it is needed for more critical functions in winter compared to summer and thus it is more challenging to cover demand during wintertime and to some extent more important that it is covered.

Technologies that do not contribute much to electricity generation at wintertime (e.g., solar power) will require the system to have an alternative generation capacity to cover the missing capacity. Technologies that have reduced generation during wintertime either due to fuel shortage or due to being intermittent in nature with less natural resources in winter (e.g., solar power) will add a burden of increasing firm capacity of the power system to ensure security of supply at wintertime.

This qualitative parameter will be assessed on three-level scale, assessing the potential of each technology for generating electricity at wintertime as having:

- Good: High potential, the ability to deliver more than 75 % of the annual capacity factor during winter times; preferred
- Medium: Moderate potential, the ability to deliver more than 40% and less than 75 % of the annual capacity factor during winter times.
- Bad: low potential: the ability to produce less than 40% of the annual capacity factor during winter times.

Electricity production at wintertime, will not be done for the actual winter period – December to February, but will be done for the colder periods of the year, which is considered to be between October and March.

1.1.21 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. Because of the current situation in UA it is valuable to know the cost efficiency both in the critical situation, where it is the production at winter time that is crucial and the technology is set up knowing that it will maybe only be operating for app. two years and there is a possibility that the technology will be in operation its full lifetime, therefore it interesting to analyze the LCOE in that context.

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 is typically €/MWh. The LCOE -as a qualitative parameter- will assess the technologies on three-level scale, the thresholds will be defined according to the distribution of the plants included, and will off course differ between the short time winter production LCOE and the lifetime LCOE:

- Good: Technologies with low LCOE, more than 20 % lower than average; preferred
- Medium: Technologies with medium LCOE less than or 20 % lower and more than or 20 % higher than average
- Bad: Technologies with high LCOE more than 20 % higher than average;

A CO_2 cost of 80 €/ton is considered in the LCOE calculations corresponding to the current (Oct. 2023) price of CO_2-allowances in the EU ETS.

1.1.22 P4: Distributed generation

Under the current situation in Ukraine, technologies that can be built in a distributed scale are more favored for a couple of reasons. Distributed generation plants offer options located near demand centers, reducing reliance on the transmission grid and mitigating the risks of losing significant power production capacity. As a significant number of large power plants, substations and grid have been targeted with air strikes, leading power loss for many consumers.

Distributed generation refers to producing electricity at or near the point of use, often using smaller, decentralized sources like gas engines, solar PV panels or wind turbines.

This qualitative parameter will be assessed on three-level scale, assessing the typical size and suitability of each technology to be used as distributed generator as technologies with typical capacities:

- Good: Technologies with capacities below 5 MW. For the scope of this technology catalogue, technologies with typical capacities below 5 MW are preferred.
- Medium: Technologies with capacities between 5-20 MW
- Bad: Technologies with capacities between 20-60 MW

1.1.23 P5: Regulation requirement in the project development process

Acquiring permits, conducting comprehensive environmental studies, and performing various assessments such as soil analysis, solar radiation evaluation, and wind condition examinations, followed by meticulous project planning and securing financial agreements, collectively entail substantial time investments. These sequential tasks significantly influence the overall timeline from project conception to initiation. Hence, it is essential to develop a comprehensive timeline that outlines the anticipated duration required for these processes, specifically tailored to the distinct technologies being employed.

This qualitative parameter is assessed on three-level scale, assessing the speed and the simplicity of the process under:

- Good: quick and easy process, less than three month; preferred
- Medium: in between process, between three month and 9 months
- Bad: lengthy and complicated process, more than 9 months.

1.1.24 P6: Delivery time / availability of components and materials

The delivery time and availability of power plant components are crucial for a fast installation. It is crucial to account for the availability of required materials (e.g. steel and cement) when considering the timeframe on constructing power generation plants.

During wartime, logistics for military operations may further delay component delivery, and essential materials like steel and cement might be scarce.

The production time for the component or the whole plant of the technology of course impacts the delivery time, if a storage of already produced components or plants exist (which e.g. is the case for PV moduls) or it is possible to by second hand plants the delivery time can be considerable reduced. Same will be the case if it found realistic that it possible to get components e.g. transformers and inverters produced for another propose also pose a possible to reduce the delivery time.

This qualitative parameter is assessed on three-level scale, assessing the delivery time and the availability of required components and material. For this scope of technology catalogue, technologies with less delivery time are favored.

- Good: delivered within less than 13 weeks (for operation winter 2023/2024); preferred
- Medium: delivered within more than 13 and less than 65 weeks (for operation winter 2024/2025)
- Bad: delivered within 65 weeks or more for operation in more than two years.

1.1.25 P7: Requirements for logistics and transportation infrastructure

War conditions affects the transportation infrastructure to a high extend, 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 three-level scale, assessing the dependency on transportation infrastructure as:

- Good: low level of demands: 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 level of demands. 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,
- Bad: high level of demands. 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 reinforcement of the roads or construction of new roads

1.1.26 P8: Technical installation time

The technical installation time is crucial because power capacity must be rapidly delivered to meet high winter demand.

The technical installation time includes the process of preparation of the building site, and all processes until the technology is commissioned.

This qualitative parameter is assessed on three-level scale, assessing the timeframe for the installation of the technology:

- Good: Installation can happen on short-term which is less than 3 months; preferred
- Medium: Installation can happen on medium-term which is between 3 months 9 months
- Bad: Installation can happen on long-term which is more than 9 months Long-term

1.1.27 P9: Requirements for skilled staff in the construction and installation phase

The successful execution of energy projects relies on the availability of staff with the necessary skills and expertise.

Environmental scientists, ecologists, meteorologists, electrical engineers, mechanical engineers, civil and structural engineers, project managers, and safety professionals could all be vital for renewable energy projects. They assess environmental impacts, design electrical and mechanical systems, ensure structural integrity, manage projects, and prioritize safety.

This qualitative parameter is assessed on three-level scale, assessing the requirements for skilled staff in the construction phase as:

- Good: Require lower skilled staff in the construction phase (low); preferred
- Medium: Require medium skilled staff in the construction phase
- Bad: Require highly skilled staff (high)

1.1.28 P10: Grid balancing capacity

Effective grid balancing is critical here due to the potential for that the existing grids is week and for 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 and supply and demand balance to maintain a reliable and stable grid operation, it could be identified by parameters as primary and secondary regulation of full load, Minimum load of full load, Warm and could start-up time, and black start up. It often involves demands for resources that can quickly respond to fluctuations in supply and demand, such as energy storage or flexible power generation sources.

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. gas power and pumped hydro, batteries; preferred

- Medium: medium ability to balance the system e.g. thermal power not gas power and wind turbines
- Bad: low ability to balance the system e.g. PV

1.1.29 P11: Requirements for electricity grid infrastructure

We assess this qualitative parameter 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
- Bad: Challenging

1.1.30 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. Furthermore, it is a question of the possibility for relying on foreign workforce.

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 risk for forced outage and longer periods of no production.

This qualitative parameter is assessed on three-level scale, assessing the requirements for skilled staff for operation and maintenance as:

- Good: do not require lower skilled staff during operation and maintenance and of specialized spare parts (low); preferred
- Medium: Require medium to highly skilled staff during operation and maintenance and of specialized spare parts, but the skilled staff and spare parts can be found in UA
- Bad: Require highly skilled staff (high) during operation and maintenance and of specialized spare parts, And the skilled staff and spare parts cannot be found in UA

1.1.31 P13: Possibility for camouflage and sheltering

The potential of distributed renewable energy technologies for camouflage and sheltering during wartime is a concept that holds significant importance in contemporary military strategies since traditional energy infrastructure often consists of easily identifiable targets, vulnerable to disruption by hostile forces.

Building distributed energy generation units underground during wartime can be a strategic and innovative approach to ensuring energy security and resilience in the face of war. Underground installations offer several advantages, including enhanced protection from enemy attacks and the preservation of critical infrastructure. Underground facilities are inherently more secure and less vulnerable to enemy attacks, including aerial bombings or sabotage. This camouflage can be crucial in preventing the targeting of vital energy infrastructure, and hence ensures the continuity of energy supply for civil and military operations, even amid war.

Distributing energy generation units across multiple underground sites can establish redundancy and reduce the risk of a single point of failure, increasing energy security. Underground installations can house a variety of renewable and conventional energy sources, including generators and battery storage, providing a diverse energy supply to meet different operational needs. Underground energy units can be remotely monitored and controlled, reducing the need for personnel to be physically present, which enhances safety during wartime.

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 three-level scale, assessing the potential for camouflage and sheltering of a specific technology as:

Low, medium, or high potential. For the scope of this technology catalogue, technologies which high camouflage and sheltering potential are favored.

1.1.32 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 that do not rely on fuels.

This qualitative parameter is assessed on three-level scale, assessing the risks associated with the fuel and spare part supply:

- Good: low risk associated, defined as no demand for fuel (e.g. PV and Wind); preferred
- Medium: medium risk associated, defined as demand for fuel that is local produced (e.g., biomass and coal);
- Bad: high risk associated, defined as demand for fuel that is not local produced e.g., natural gas and oil;

APPENDIX B: LCOE CALCULATIONS

The calculation of the Levelized cost of electricity (LCOE), has been done by dividing the expenditures into the following categories, capital expenditure, operational expenditure, finance costs, fuel costs and CO_2 costs.

Every category supplies the expenditures per unit 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 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 WTG production for each Ukrainian region is mapped. For plants that rely on fuels, the expected full load hours are expected to be 3500 in the cold period and 5000 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 Danish technology catalogue 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_2eq 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_2eq 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%.

APPENDIX C: CROSS CUTTING ISSUES

1.1.33 Grid related issues

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 include:

i) Missile/drone attack on grid substations, transformer stations, transmission, and distribution lines
ii) Dropout of large demand facilities
iii) Lack of information exchange capability in some areas
iv) Limited or temporary capability for control and monitoring of the grid system.

Recommended power generation technologies must have the capability to function in grid scenarios with intentional islanding, operating in a more distributed and autonomous manner. This is essential due to potential disruptions in communication and monitoring capabilities, including dropouts and extended periods of no data connection. Additionally, attacks from hackers are quite intense in the UA data communication system. Therefore, robustness requirements for information security should be one of the highest priorities for new power generating systems, in order to secure the power supply even in isolated grid situations.

Challenges related to 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 these technologies.

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 favorable 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 and solar power, it is essential to operate the system with maximum flexibility, as close to the time of production as possible.

Adjustments to the balancing time window could potentially create a better VRE integration. While conventional generation portfolios typically operate with a 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.

When addressing the necessity of flexibility, it is worth noting that hydroelectric power plants (HPPs) with dams and pumped storage are already installed in Ukraine. HPPs can add a large amount of flexibility to the UA energy system. HPPs are already used as storage systems for balancing and integrating variable renewable energy sources in parts of the Northen and Central European energy systems.

Another issue brought op in the interview is the practice of curtailing solar generation in September, this suggests that an optimal dispatching based on least cost 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 a better forecasting of VRE to ensure a smart operation of the energy technologies.

1.1.34 Financial issues

Under the current situation there could be some special requirement 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.

1.1.35 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 further that power is transmitted, the higher the voltage levels.

Furthermore, transformers are also used to step down the power levels, to stages until it 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.

Category	Apparent power rating	Weight	Description
Small transformers	<500 kVA	1kg – 2 tons	Transformers used in residential neighborhoods
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 <	70-400tons	Used for major substations and power generation plants -Step up

Table 19 : Transformers categories and their key parameters

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 that 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 around 1-2 years whereas small transformers may be supplied within a couple of weeks.

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

Table 20: Estimated delivery time per transformer's category

APPENDIX D: METHODOLOGY FOR DETERMINING PV RESOURCE POTENTIALS IN UKRAINE

Calculation methods and assumptions for the charts

This section refers to the Figure 11 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 1994-2018, 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 10 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 was used. These raster maps contained the daily potential production average from 1994-2018, for each of the corresponding months. Meaning that the daily values, was an average aggregate of the days in the corresponding month. Therefore, the daily values for each month, was 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 the 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 100km and 280km 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.

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[11]. 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 has been supplied by the European Centre for Medium-Range Weather Forecasts. The ERA5 datasets are obtained through satellite measurements, that has been validated by radar measurements. The capacity factor is based on the average aggregate of the wind speeds between the year 2008-2017. The capacity factor is given as a pixel containing a value, which 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 was calculated, by using the wind turbine provided in the technology catalogue as a reference. The generating capacity for that wind turbine is 4,2MW, with a hub height of 85m and rotor diameter of 130m. The raster map, containing the capacity factor of IEC2 class turbines was used, as the wind turbine in the technology catalogue is a 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 100km and 280km was applied from Russian controlled areas and Belarus, accounting

---

[11] 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: https://www.lmwindpower.com/en/stories-and-press/stories/learn-about-wind/what-is-a-wind-class 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.

APPENDIX F: DATA SHEETS

Data sheets is attached in a excel sheet.

APPENDIX G: LOCAL CONSIDERATION

Local consideration for PV residential rooftop in Ukraine

In Ukraine, consumers can install electricity generation units for self-consumption without a license, if they do not supply excess energy to the Wholesale Electricity Market or other networks. They can also use energy storage systems without a license, provided they don't release stored energy into the Wholesale Electricity Market or other networks. Households with feed-in tariff agreement can sell their electricity to the universal service provider, while other consumers, including energy cooperatives, can sell to the off-taker (i.e., The Guaranteed Buyer).

In June 2023, Ukraine passed Law[12] No 3220, introducing the concept of an active consumer (prosumer) and enabling them to qualify for the net billing support scheme. An active consumer status is achieved by signing electricity purchase and sale agreements under the self-generation mechanism, agreements with guaranteed buyers or universal service providers for selling electricity at a feed-in tariff, or by installing an energy storage system for participation in ancillary services and the purchase/sale of stored electricity. Under the net billing mechanism, if a household uses an energy storage system, electricity sales occur at the market price (e.g., 0.071 EUR/kWh in June 2023).

Law No 3220 aims to encourage private households to install renewable energy generating units through self-generation mechanisms. To achieve this, a state target economic program was planned, but it hasn't been adopted by the Cabinet of Ministers as of October 2023. The program should motivate private households to install generating units up to 10 kW, along with energy storage systems at a ratio of 1 kW capacity to at least 0.5 kWh storage capacity. Stimulation measures for households could come in two forms: the feed-in tariff and the net billing system.

Local consideration for PV commercial, industrial, and public rooftop in Ukraine

In Ukraine, accompanying non-residential PV rooftop with battery storage, particularly for non-industrial purposes, is considered due to energy security measure. In the national level, Law 3220 has been enacted, focusing on net-billing and related issues. In the commercial and public sectors, this law is anticipated to encourage solar station installations by enabling surplus electricity feed-in and withdrawal as needed, potentially boosting the

[12] https://zakon.rada.gov.ua/laws/show/3220-20#Text : The Law of Ukraine regarding restoration and "green" transformation of the energy system of Ukraine.

solar energy sector.

Once Law 3220 is enforced, the process of feeding surplus electricity from non-residential PV rooftop into the grid will require coordination. Unusual scenarios, such as multiple power lines for non-residential facilities like hospital complexes, where several buildings are connected to separate lines linked to the distribution system operator substation, may pose challenges. In such cases, transferring electricity between buildings without the involvement of the distribution system operator might not be feasible, necessitating the installation of a separate cable line. For example, if solar panels are installed on one building, and excess capacity is available to power nearby buildings, technical coordination with the distribution system operator may be necessary. In practical terms, facilities like hospitals and public buildings, which can only meet a portion of their electricity needs with solar panels, may not find it beneficial to pursue a Feed-In Tariff arrangement. While using batteries for energy storage is desirable, the absence of economic incentives currently discourages their installation.

Amidst the war's impact on Ukraine's energy infrastructure, the EU has launched the "Ray of Hope" project, planning to donate 5,700 PV panels to the country. These panels will be primarily deployed in critical infrastructure sites such as hospitals, fire departments, and schools. Each site's installed capacity will not surpass 2 MW, contributing to energy resilience and support for vital services during these challenging times.

Local consideration for PV utility-scale in Ukraine

The government's current drive to encourage market participation encounters resistance from some companies due to market uncertainties, ongoing warfare, and price restrictions. These factors pose substantial barriers to investment in the renewable energy sector.

To genuinely establish a sustainable renewable energy infrastructure and seamlessly integrate it into the power grid, comprehensive planning, well-defined mechanisms, long-term investment safeguards, and robust support mechanisms are essential. It's widely acknowledged that the predominant risk currently is the ongoing war, further emphasizing the importance of comprehensive insurance solutions. Addressing this risk requires collaborative efforts between the state and businesses.

According to the interviewed local experts, there are around 650 licensees for large-scale solar PV installation in Ukraine, with approx. 40 professional companies working in the field.

In Ukraine, the construction of utility-scale solar power installations can be accomplished relatively swiftly. The construction time for a turnkey 1 MW station is approximately three months, while a larger station with a capacity of 10-15 MW typically takes around five months. For instance, the DTEK Pokrovska Solar Power Plant, which included 240 inverters and 320 panels, was successfully built in just nine months. The construction teams worked on-site, sometimes using robotic assistance, even during nighttime hours, with three different contractors involved in the project. This experience has enabled Ukrainians to develop both speed and quality in solar power construction, as they have learned from previous mistakes and continually improved their practices.

Large-scale solar installations offer a considerable advantage in terms of physical protection during military hostilities. These installations are distributed over extensive territories, making it highly impractical and costly to destroy them through direct attacks. In case of direct hits, only individual modules, such as 100 kW of panels, may require replacement, and the overall station can continue functioning. Potential issues might arise at the substations, which are now often containerized and can be easily installed and connected. Solar stations, as a technology, exhibit inherent resistance to warfare, and it is typically neither sensible nor economical to deploy air defence systems to protect solar parks.

Instances of solar station damage have primarily occurred in occupied territories or areas where direct military actions have taken place, such as tank movements or rocket strikes, or in areas where there were suspicions of hidden activity. Solar power technology has shown its resilience in the face of adversity. A 3.9 MW solar plant located in Ukraine's Kharkiv region, the largest utility-scale solar station in the area, was partially damaged during a Russian missile attack on May 28, 2022. Despite the damage to 416 solar panels and four inverters, the station was able to partly resume operations. The staff managed to disconnect the damaged components, allowing the plant to contribute 1.8 MW of clean electricity to the grid. This solar plant is situated 30 km south of Kharkiv and provides power to the city of Merefa, serving as an example of distributed generation aimed at supplying energy to a small town. The station features Talesun 325 W PV modules and 27 kW Fronius ECO 27.0-3-S string inverters, showcasing its capacity for resilience despite typical damage caused by rocket or projectile impacts in the region. The solar park’s unique foundation on a swampy area using geo-screws allowed it to withstand local damage to supporting structures following the missile attack.

Figure 25: The Merefa solar park in Kharkiv region partially damaged by Russian attacks. Photo by: Solar Generation

Figure 26: Solar Park in Kharkiv partially damaged by Russian attacks. Photo by: Solar Energy Association of Ukraine

According to local experts, the supply of equipment to Ukraine for solar power projects does not appear to be affected by the ongoing war. Equipment has been imported and transported by truckloads, even for larger installations up to 7 MW parks. Additionally, imports through Romania using Romanian ports have been utilized without significant issues. Solar power projects have been able to receive the necessary equipment from these sources and successfully build and connect their installations.

According to local experts, the construction of a solar station in Ukraine typically takes an average of 3-4 months. For a larger installation like a 5 MW station, it might take up to six months. In terms of project development speed, Ukraine is more efficient than Europe, although there are specific nuances that need to be addressed. However, due to the ongoing war and past issues with government commitment fulfilment, companies may face challenges in accessing financial resources.

URGENT TECHNOLOGY CATALOGUE FOR THE UKRAINIAN POWER SECTOR
DECEMBER 2023 – VERSION 1.2

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

- MAN Energy Solutions
- RWE Scandinavia
- TOWII Renewables
- Better Energy
- Hybrid Greentech Energy Intelligence
- ABB – Hitachi
- Schneider Electric
- SGB Smit
- Siemens Energy
- BWSC

LIST OF ABBREVIATIONS

Abbreviations	Definitions
€	Euro
AC	Alternating current
BOS	Balance of System
LCOE	Levelized cost of electricity
CAPEX	Capital expenditure
CBRM	Close-range ballistic missiles
CHP	Combined heat and power
CO2	Carbon dioxide
DC	Direct current
EIA	Environmental impact assessment
ESCO	Energy service companies
ESS	Energy storage systems
EUR	Euro
FGT	Flue gas treatment
FLH	Full load hours
GW	Gigawatt
HPP	Hydro power plant
HPP	Hydroelectric power plants
HVAC	Heating, ventilation, and air conditioning
IBRD	International Bank for Reconstruction and Development
IEC	International Electrotechnical Commission
IFC	International Finance Cooperation
kg	Kilogram
kW	Kilowatt
kW_e	Kilowatt electric
kWh	Kilowatt-hour
LCOE	Levelized Cost of Electricity
LIB	Lithium-ion batteries

LTE	Life time extension
m	Meter
m^2	Square meter
MoE	Ministry of Energy
MW	Megawatt
MW_e	Megawatt electric
MWh	Megawatt-hour
MWp	Megawatt power
MWth	Megawatt thermal
NCSREPU	National Commission for State Regulation of Energy and Public Utilities
NG	Natural gas
NOx	Nitrogen oxides
O&M	Operation and maintenance
OPEX	Operating expenses
ORC	Organic Rankine cycle
P1, P2, etc.	Parameter 1, Parameter 2, etc.
PCED	Project and Cost Estimate Documentation
PJ	Petajoule
PPA	Power purchase agreement
PV	Photovoltaics
Q	Implementing speed (how quick this could be done)
R	The resilience of selected technologies
RoR	Run of river
s	Second
SCR	Selective Catalytic Reduction
TEFS	Technical and Economic Feasibility Study
TMS	Thermal management system
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