UKRAINE: MAPPING THE ENERGY OPPORTUNITIES

SOLAR AND WIND ENERGY ASSESSMENT

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Solar and Wind Energy Assessment

Report erstellt im Auftrag von Greenpeace e.V.

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The Institute for Sustainable Futures (ISF) was established by the University of Technology Sydney in 1996 to work with industry, government and the community to develop sustainable futures through research and consultancy. Our mission is to create change toward sustainable futures that protect and enhance the environment, human wellbeing and social equity. We seek to adopt an inter-disciplinary approach to our work and engage our partner organizations in a collaborative process that emphasizes strategic decision-making.

For further information visit: www.isf.uts.edu.au/oecm

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This project has been conducted in cooperation with Greenpeace Germany, Hongkongstraße 10, 20450 Hamburg, Germany.

CITATION

Teske, S., Miyake, S (2024) Ukraine: Solar and Wind Energy Assessment; prepared for Greenpeace Germany by ¬The University Technology Sydney, Institute for Sustainable Futures; April 2024

ACKNOWLEDGEMENTS

The authors gratefully acknowledge data and advice contributed by Greenpeace Germany.

All conclusions and any errors that remain are the authors own.

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Introduction

“Solar and wind energy mapping for Ukraine”

Russian attacks on Ukraine have inflicted significant suffering on the civilian population and turned many people's lives upside down. A secure supply with heat and electricity became a major challenge to many households in Ukraine as Russia systematically attacks critical infrastructure. This dire situation puts an immediate increase of the country’s energy resilience to the forefront of the political agenda.

From the Greenpeace perspective, shared by many other organizations and experts, renewable energies can play apivotal role here. This particularly applies to the expansion of solar and wind energy, because these technologies can make by far the largest, the cheapest and the most environmentally friendly contribution to renewable energies. Furthermore, the expansion of wind and solar offers enormous economic prospects. Given Ukraine’s outstanding size and land area, the country has the potential not only to be self-sufficient in energy supply, but it can also become a bigger exporter of green electricity and hydrogen. Additionally, there is great political interest in energy cooperation and trade with the states of the European Union.

In light of these considerations, we commissioned the renowned scientists from the Institute for Sustainable Energy Future from Sydney to assess and calculate the potential of solar and wind energy in Ukraine. Their results are remarkable and will hopefully fuel the discussion about the direction of Ukrainian future energy policy. The potential of solar and wind energy remains largely underestimated in the Ukrainian government and discussion. The results also strengthen the idea of a stronger cooperation with Europe in energy supply and encourage Ukrainian communities and people to increasingly take their energy supply and future into their own hands.

Andree Boehling

Energy Expert, Greenpeace Germany

Executive Summary

What role can solar and wind energy play in the Ukraine?

Greenpeace Germany has commissioned the Institute for Sustainable Futures (ISF) at the University of Technology Sydney (UTS) to analyse the solar and wind potential of the Ukraine on the basis of digital Geographic information system (GIS) maps. The primary purpose of GIS mapping is to ascertain the solar and wind energy resources available. It also contributes to the regional analysis of geographic and demographic parameters and the available infrastructure that can be leveraged in developing energy scenarios. The comprehensive data set of the solar and wind energy potential for the Ukraine is aimed to support a 'Green Rebuild' concept. The GIS data of this analysis in a 250m-by-250m resolution is available to all government institutions of the Ukraine.

Solar and wind mapping under two scenarios

The average annual solar irradiation (DNI) level in Ukraine is between around 950 and 1500 kWh/m^2 per year, and the higher end of that range is in the southern part of the country. The overall wind resources on land are lower in the Ukraine compared with the solar potential. The wind speeds in Ukraine range from 1.3 to 12.5m/s at 100 m height (Global Wind Atlas). In this analysis, we have included only areas with an average annual wind speed of ≥ 5 m/s. Ukraine's wind potential has been mapped under two different scenarios. The current use of wind energy in Ukraine involves utility scale wind turbines in the range up to 10 kilowatts, operated both on- and off-grid as battery chargers.

Ukraine's solar and wind potential has been mapped under two different scenarios.

'Scenario 1': Available land—restricted by protected areas (PA), topography (slope > 30%, S30), and existing land use, including forests and urban areas (LU).

'Scenario 2': See 1, with the additional restriction excluding areas ≤ 10 km from existing transmission lines (PT10) (Figure 5).

Open forest, shrubs, herbaceous vegetation, bare/sparse vegetation, and agricultural land were included in the available land (LU) for the two wind scenarios, whereas the land-cover classes closed forests, wetland, moss and lichen, urban/built up areas, snow and ice, and permanent water bodies were excluded in this analysis of wind potential.

Based on the suitable land-area, the potential installed capacities and possible electricity generation per year has been calculated (Miyake, 2023)[1]. For utility scale solar, it is assumed that on each square kilometre a capacity of 25 MW solar photovoltaic modules with an average efficiency of 18% can be installed. Higher efficiencies would decrease the amount of space for each MW further. Furthermore, space for access roads and working lanes are included and therefore not the entire land-area can be used for solar modules. In case of agricultural solar pv project, the modules are installed high above the ground and the same space can be used for food production and/or other crops for bioenergy or bio material production.

For onshore wind, it is assumed that 2 MW to 3 MW turbines are installed and that the distance between wind generators is around 6 to 7 times the rotor diameter. A standard three-blade, upwind, horizontal axis 3 MW wind turbines has an average rotor diameter of 115m to 140m (depending on the model and if those are coastal or inland optimized machines). Thus, the average installed capacity per square kilometre is assumed with 5MW. Utility scale solar and wind turbines can be combined on the same land therefore the energy unit based solar and wind potential can be added up. However, due to the vast potential, solar and wind projects might usually not be on the same block of land.

1% of the suitable land for solar and wind can supply Ukraine's entire electricity demand

The Ukraine has an enormous solar and wind energy potential that exceeds current electricity demand (125 TWh/a)– even under conservative land-use restriction – close to 150 times over. Thus, only a small percentage of the theoretical suitable land for utility solar and onshore wind is required to supply the entire country with electricity.

Even under the assumption, that a future full decarbonization of Ukraine's energy supply will triple or even quadruple due to increased electrification of the transport sector, residential space heating with heat pumps and industrial process heating via synthetic fuels such as hydrogen and ammonia as well as industrial scale heat pumps, the renewable electricity potential does

[1] Miyake 2023, https://mangomap.com/university-of-technology-sydney/maps/132307/solar-potential-area-in-g20?preview=true# and https://www.uts.edu.au/oecm/renewable-resource-mapping

not provide any limitations. Furthermore, besides solar and onshore wind, the Ukraine can utilize offshore wind, bio energy, geothermal energy and hydro power. However, the potential analysis for those sources were out of scope for this research.

The energy economic importance of Ukraine solar and onshore wind electricity generation potential becomes clear when compared to its domestic electricity demand. Under the assumptions of scenario 1, only 0.46% of the solar and 0.4% of the wind potential, would be sufficient to supply the entire country with electricity. Under the more realistic assumption to utilize only land within a proximity of 10 km from a high voltage line, the Ukraine could generate its final electricity demand (2021) with only 1% of its suitable land area for solar and wind installations.

Ukraine – solar and wind potential in comparison to domestic demand

Ukraine (with Crimea) Electricity demand in 2021: 125 TWh/a	Solar Potential Installed Capacity	Solar Potential Annual Generation (Capacity Factor 12%)	Wind Potential Installed Capacity	Wind Potential Annual Generation (Capacity Factor 35%)	Solar + Wind Potential Installed Capacity	Solar + Wind Potential Annual Generation	Supply Factor (Solar + Wind)
	[GW]	[TWh/a]	[GW]	[TWh/a]	[GW]	[TWh/a]	[1]
Scenario 1 - theoretical suitable area	11,301	11,866	2,146	6,546	13,447	18,460	148
Scenario 2 - grid proximity 10km	5,084	5,339	950	2,897	6,034	8,257	66

The Ukraine can export renewable electricity to the EU

Ukraine's significant solar and onshore wind resources cannot only be utilized for domestic supply, but also for energy exports to the neighbouring countries. The energy can be exported either in form of electricity via power grid, or in form of hydrogen, synthetic fuels – produced with renewable electricity – via pipelines or tanker over land or sea.

To put Ukraine's solar and onshore wind potential into a European perspective, the results are compared with renewable energy potentials for the EU27 and selected European countries which served as a basis for 1.5˚C Paris aligned decarbonization pathways, a research project for the United Nations Finance Initiative and the UN-convened Net Zero Asset Owners Alliance undertaken in 2023 (Teske et. al. 2023)[2]. The table below shows the solar and onshore wind potential, both in regard of the installed capacity in *Gigawatt* [GW] as well as the expected average annual generation in *Terawatt hours per year* [TWh/a]

Ukraine – solar and wind potential in comparison to the European Union (EU27) and selected member countries

	Solar Potential Installed Capacity	Solar Potential Annual Generation (Capacity Factor 12%)	Wind Potential Installed Capacity	Wind Potential Annual Generation (Capacity Factor 35%)	Solar + Wind Potential Installed Capacity	Solar + Wind Potential Annual Generation	Current electricity demand
	[GW]	[TWh/a]	[GW]	[TWh/a]	[GW]	[TWh/a]	[TWh/a]
Ukraine (with Crimea)		1,051		3,066			125
Scenario 1 - theoretical suitable area	11,301	11,880	2,146	6,580	13,447	18,460	
Scenario 2 - grid proximity max 10km	5,084	5,345	950	2,912	6,034	8,257	
France (G20 & G7)	6,641	6,981	1,249	3,829	7,890	10,810	444
Germany (G20 & G7)	1,446	1,520	699	2,143	2,145	3,663	527
Italy	3,970	4,173	249	764	4,219	4,936	281
United Kingdom	28.3485	29.7999432	599.27	1837.36182	627.6185	1,867	283
EU27 Total	34,400	36,162	6,630	20,329	41,031	56,490	2,564

New infrastructure for energy import in the EU required

Exporting renewable electricity or renewable-energy based gases and fuels requires dedicated energy infrastructure – designed for export. The capacity of high voltage power lines must be significantly larger than those designed for limited electricity trading with neighbouring countries. The Ukraine currently has power grid connections with four EU member countries – Poland, Slovak Republic, Hungary and Romania – which can be utilized to import renewable electricity into EU. Figure 7 shows Interconnectors and electricity grids between the Ukraine and its neighbouring countries.

[2] Teske et. al. 2023, Teske, S., Rispler, J., Niklas, S. et al. Net-zero 1.5 °C sectorial pathways for G20 countries: energy and emissions data to inform science-based decarbonization targets. SN Appl. Sci. 5, 252 (2023). https://doi.org/10.1007/s42452-023-05481-x

Renewable energy can create close to 20,000 new jobs for the Ukraine by 2030

Finally, renewable energies provide long-term job opportunities. According to the International Renewable Energy Agency (IRENA), the renewable energy industry provides 13.7 million globally in 2023, 1 million more than in 2022. About 4.9 million jobs were in the solar photovoltaic industry, followed by around 2.5 million jobs both in the hydro power and bio fuels industry and 1.4 million jobs in the wind industry (IRENA 2023B[3]).

In order to estimate the approximate job potential, a very simple market development scenario for the Ukrainian solar and wind industry was adopted: It was assumed that by 2030 the market for new installed solar and wind systems would be back to the level of 2021 and then increase continuously over the next 20 years with robust annual market growth. The table below shows the simplified employment potential estimation and the assumed solar and wind market development. This calculation is strictly indicative, and a more detailed energy scenario development and industry assessment is required.

Green Rebuild – Solar and Wind development scenario

					Projection >>>									
Ukraine	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2035	2040	2050
Cumulative Installed capacity in [MW]														
Solar PV	6,075	6,381	6,381	6,381	6,681	7,026	7,440	7,947	8,622	9,532	10,762	20,452	36,275	102,798
Onshore wind	1,314	1,672	1,672	1,672	1,872	2,092	2,340	2,624	2,959	3,377	3,889	8,168	15,177	44,646
Annual Installed Capacity in [MW/a]														
Solar PV	1,239	1,301	0	0	300	345	414	507	675	911	1,229	2,356	3,795	9,842
Onshore wind	358	456	0	0	200	220	248	285	334	418	512	1,044	1,681	4,360
Annual Growth Rate in [%/a]														
Solar PV	25.6%	5.0%	0.0%	0.0%	10.0%	15.0%	20.0%	22.5%	33.0%	35.0%	35.0%	10.0%	10.0%	10.0%
Onshore wind	12.3%	27.2%	0.0%	0.0%	10.0%	10.0%	12.5%	15.0%	17.5%	25.0%	22.5%	10.0%	10.0%	10.0%
Implemented share of Potential 'Scenario 2' - [%]														
Solar PV	0.12%	0.13%	0.13%	0.13%	0.13%	0.14%	0.15%	0.16%	0.17%	0.19%	0.21%	0.40%	0.71%	2.02%
Onshore wind	0.14%	0.18%	0.18%	0.18%	0.20%	0.22%	0.25%	0.28%	0.31%	0.36%	0.41%	0.86%	1.60%	4.70%
Extrapolated employment potential in [Job years]														
Solar PV	10,076	10,583	4,467	4,467	6,087	6,540	7,154	7,947	9,205	10,952	13,311	25,390	43,227	118,216
Onshore wind	2,685	3,417	502	502	1,842	2,036	2,286	2,609	3,028	3,688	4,444	9,130	15,311	41,297
Solar & Wind Jobs - total	**12,761**	**14,000**	**4,968**	**4,968**	**7,928**	**8,575**	**9,440**	**10,555**	**12,233**	**14,641**	**17,755**	**34,520**	**58,538**	**159,513**

Conclusion

The Ukraine can generate its entire domestic electricity demand with solar photovoltaic and onshore wind power plants on only 1 percent of the suitable land. Furthermore, the Ukraine has a significant export potential for renewable electricity in countries of the European Union. To utilize this significant economic potential, existing power lines need to be strengthened and new power lines must be built to connect the Ukraine closer to the EU.

Renewable energy can provide new income for the Ukraine economy and could create new jobs and long-term employment opportunities.

[3] IRENA 2023B, IRENA and ILO (2023), Renewable energy and jobs: Annual review 2023, International Renewable Energy Agency, Abu Dhabi and International Labour Organization, Geneva, ISBN: 978-92-9260-552-0,

Background: The One Earth Climate Model (OECM)

Beyond reasonable doubt, climate change over the last 250 years has been driven by anthropogenic activities. In fact, the human-induced release of greenhouse gas emissions into the atmosphere warms the planet even more than is currently observed as climate change, but some of that greenhouse-gas-induced warming is masked by the effect of aerosol emissions. Carbon dioxide emissions are so large that they are the dominant driver of human-induced climate change. A single kilogram of CO_2 emitted will increase the atmospheric CO_2 concentration over hundreds or even thousands of years.

The Paris Climate Agreement '*notes that (…) emission reduction efforts will be required (…) to hold the increase in the global average temperature to below 2˚C above pre-industrial levels (…)*'. The Intergovernmental Panel on Climate Change (IPCC) further quantified the carbon budget to achieve this target in its Sixth Assessment Report of the Working Group. According to the IPCC, a global carbon budget of 400 $GtCO_2$ is required to limit the temperature rise to 1.5˚C with 67% likelihood by 2050. To accomplish this, countries have submitted Intended Nationally Determined Contributions (INDCs) outlining their post-2020 climate actions. To implement the required ambitious targets, energy- and climate-mitigation pathways are required.

In 2017, the Institute for Sustainable Futures (ISF) at the University of Technology Sydney (UTS) started an interdisciplinary reach project[4] to develop practical pathways to achieve the Paris climate goals based on a detailed bottom-up examination of the potential of the energy sector, in order to avoid reliance on net negative emissions later. This research was published first in form of a 500-page open access book in February 2019 at Springer[5]. In 2022, a second book was published which laid out detailed pathways for over 20 industry sectors such as the chemical industry, steel production as well as the cement and aluminium industry.[6]

The OECM focuses on the development of decarbonisation pathways with high technical and geographical resolution. Furthermore, the OECM also considers the development pathways for non-energy-related emissions and mitigation measures for them because it is essential to address their contributions if we are to achieve the Paris climate change target.

Scenario studies cannot predict the future. Instead, scenarios describe what is required for a pathway that will limit warming to a certain level and is feasible in terms of technology implementation and investment. Scenarios also allow us to explore the possible effects of transition processes, such as supply costs and emissions. The energy demand and supply scenarios described in this study have been constructed based on information about current energy structures and today's knowledge of energy resources and the costs involved in deploying them. As far as possible, the One Earth Climate Model (OECM) research also considers potential regional constraints and preferences.

Besides country specific 100% renewable energy scenarios, ISF expanded the methodology and is now able to develop energy pathways consistent with the 1.5˚C Paris Climate Agreement requirement for specific industry sectors such as *Steel, Aluminium and Chemical Industry.* In 2022, the One Earth Climate Model (OECM 2.0) was the only integrated energy assessment model with the highest resolution in regard to industry sectors, residential energy demands, transport and geographical breakdown. To meet the needs of developing countries, the OECM 2.0 can also develop specific pathways for cooking devices with high technical detail ranging from open fire cook stoves to electric induction cook stoves.

Since the research project started, the University of Technology Sydney–Institute of Sustainable Future (UTS-ISF) has undertaken detailed country-specific energy analyses, ranging from the global south, including Tanzania, to industrialized nations.

The One Earth Climate Model covers all research fields required to develop a detailed energy pathway, ranging from solar, onshore and offshore wind potential, demand projections for over 20 different industry and service sectors, commercial and residential buildings and transport from aviation and shipping and rail and road transport for passengers and fright.

This research is focused on the first step of the OECM concept – the solar and wind potential analysis.

[4] In cooperation with the German Aero Space Center (DLR) and the University of Melbourne

[5] Teske, S. et al. (2019). Methodology. In: Teske, S. (eds) Achieving the Paris Climate Agreement Goals. Springer, Cham. https://doi.org/10.1007/978-3-030-05843-2_3

[6] Teske S (ed.) (2022) Achieving the Paris Climate Agreement Goals (part 2). Springer, Cham. https://doi.org/10.1007/978-3-030-99177-7_1

Research Scope

The UTS/ISF energy analysis with the One Earth Climate Model (OECM) cover the following aspects:

1. Solar energy resource analysis based on GIS data under constrained land availability conditions. Land areas such as protected areas, areas with a steep slope, and certain land-cover classes, such as closed forests, wetlands, and permanent water are excluded.
2. Onshore wind energy resource analysis based on GIS data under constrained land availability conditions. Land areas such as protected areas, areas with a steep slope, and certain land-cover classes, such as closed forests, wetlands, permanent water, urban built-up areas are excluded.
3. Global trends for the power sector:
    - Market trends for power generation
    - Technical article: State of the art decentralized power generation and security of supply
4. Development of a power point presentation and online presentation at high level event

TECHNICAL APPROACH AND METHODOLOGY

UTS-ISF developed a multi-layer methodology for country and sector specific energy pathways. The entire modelling process is based on four modules developed by UTS-ISF and connected to the *One Earth Climate Model (OECM).* In this research project, only the first module of the OECM will be used: The solar and wind potential analysis tool '[R]E-SPACE'.

The primary purpose of GIS mapping is to ascertain the solar and wind energy resources available. It also contributes to the regional analysis of geographic and demographic parameters and the available infrastructure that can be leveraged in developing the scenarios.

The mapping has been performed with the computer software 'ArcGIS', which analyses and edits spatial information and constructs and exports graphical maps. It will be used to allocate solar and wind resources and for demand projections for each calculated region. Population density and the distribution of economic activities and their projections, are key input parameters in the region-specific energy analysis.

PROJECT DESCRIPTION

Development of a comprehensive solar and wind energy potential for the Ukraine as a basis for a 'Green Rebuild' concept. The GIS data of this analysis in a 250m-by-250m resolution will be made available the client and the Ukraine government.

An expose about the latest trends in the power sector such as technology trends in power generation, cost developments over the past years and grid integrated and stand-alone microgrids is part of the second work package.

The analysis aims to lay to foundation of a detailed energy demand and supply concept for the Ukraine.

WORK PACKAGES

The scenario development will be broken down in the following work packages

I. Data gathering, Renewable Resources Assessment

II. Sector analysis – global trends in power generation and decentralized power supply

III. Presentation and publication

1 Ukraine: Renewable Energy Potential

Ukraine's solar and wind potential was assessed as an input for future energy scenario developments. In this section, we assess the technical potential under space-constrained conditions.

1.1 THE [R]E SPACE METHODOLOGY

The [R]E Space methodology is part of the One Earth Climate Model (OECM) methodology. GIS mapping was used to ascertain Ukraine's renewable energy resources (solar and wind). It was also used in the regional analysis of geographic and demographic parameters and the available infrastructure that could be leveraged in developing the scenarios. Mapping was performed with the software ESRI ArcGIS10.6.1, which allows spatial analysis and maps the results. It was used to allocate solar and wind resources and for the demand projections for the seven modelling regions. Population density, access to electricity infrastructure, and economic development projections are key input parameters in ta region-specific analysis of Ukraine's future energy situation, to clarify the requirements for additional power grid capacities and/or micro-grids.

The [R]E Space methodology is part of the One Earth Climate Model (OECM) methodology to map solar energy potential and onshore energy potential. Open-source data and maps from various sources were collected and processed to visualize the country, its regions, and districts. Further demographic data related to the population and poverty were plotted on the maps together with transmission networks and power plants. The main data sources and assumptions made for this mapping are summarized in Table 1.

Table 1: Ukraine—[R]E 24/7—GIS-mapping—data sources

Data	Assumptions	Source
Land cover	Land cover classes suitable for solar energy and wind energy production were identified from Copernicus Global Land Cover 2019.	Copernicus Global Land Cover - 2019[7]
Digital Elevation Model (DEM)	For both wind and solar analyses, any land with a slope of > 30% was excluded from all scenarios.	SRTM Digital Elevation Data Version 4 [8]
Protected Areas	All protected areas designated national parks, wildlife reserves, hunting reserves, conservation areas, or buffer zones were excluded from all scenarios.	World Database on Protected Areas [9]
Solar Irradiance (direct normal irradiation: DNI)	The average yearly direct normal insolation/irradiation (DNI) values range from 1 to 5 MWh/m^2 per year (2.7–13.6 kWh/m^2 per day).	Global Solar Atlas [10]
Wind Speeds	Wind speeds ≥ 5 m/s were considered at a height of 100 m.	Global Wind Atlas [11]

The [R]E Space mapping procedure is summarised in Figure 1. The land areas available for potential solar and wind power generation were calculated and visualized at the national and provincial levels using ArcGIS. The land-cover map, elevation (digital elevation model: DEM), World database of protected areas, solar irradiation (direct normal irradiation: DNI) and wind speed data were obtained from the website cited above as raster data, and were all converted into binary maps (0 = area not suitable as a potential area, 1 = area suitable as a potential area) against all the assumptions in Table 1, and then combined into one binary map by overlaying all the raster data. This map integrates all the criteria listed cited above in one map with a value of 1 (land included in the potential area) or a value of 0 (land not included in the potential area).

7 Copernicus Global Land Cover – 2019: https://land.copernicus.eu/global/products/lc
8 SRTM Digital Elevation Data Version 4: https://srtm.csi.cgiar.org/
9 World Database on Protected Areas: https://www.protectedplanet.net/en/thematic-areas/wdpa?tab=WDPA
10 Global Solar Atlas: https://globalsolaratlas.info/map
11 Global Wind Atlas: https://globalwindatlas.info/en

Data on transmission lines and protected areas exist as vector data. All protected areas were excluded from the above value 1 area in the integrated raster data using a mask layer generated from the 'erase' function. For scenario 2, buffer layers were generated from transmission line (10 km) data, and then the raster data without protected areas were clipped by these buffer layers to generate potential area maps under Scenario 2. This input was fed into the calculations for the [R]E 24/7 model, as described below.

Disclaimer: The environmental criteria used to identify suitable areas for utility scale solar and wind projects do not reflect the current legislation in Ukraine, and the potential provided is a conservative estimate and may ultimately be larger.

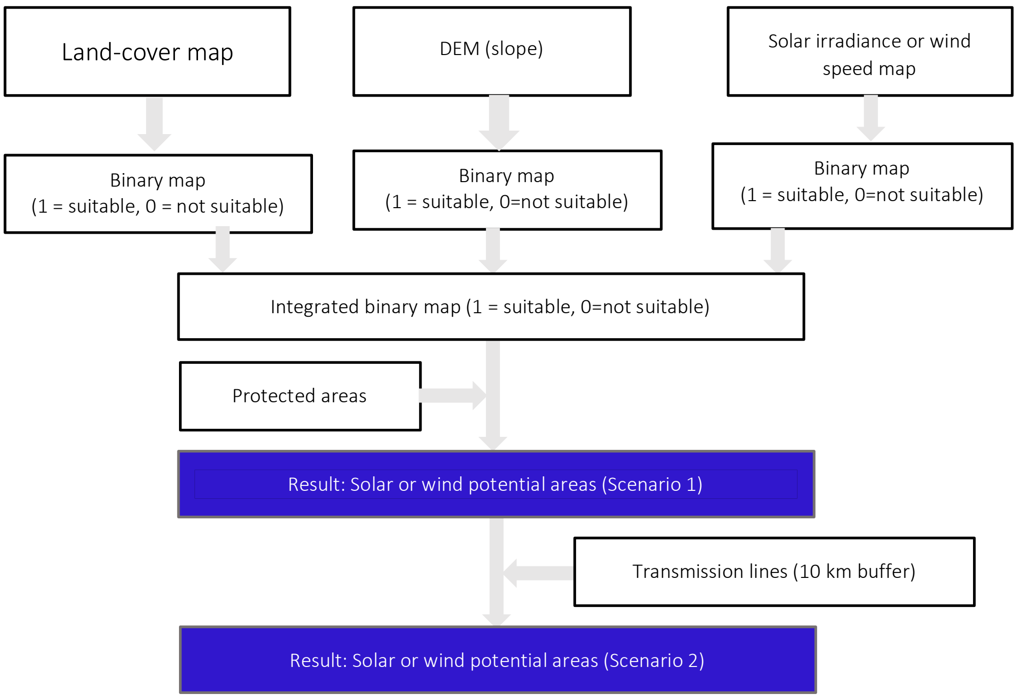


Figure 1: [R]E Space Methodology—solar potential analysis and wind potential analysis

1.1.1 THE [R]E SPACE – ASSUMED LAND USE RESTRICTIONS

RE-SPACE is based on a Geographic Information Systems (GIS) approach and provides maps of the solar and wind potentials in space-constrained environments. GIS attempts to emulate processes in the real world, at a single point in time or over an extended period. The primary purpose of GIS mapping is to ascertain the renewable energy resources (primarily solar and wind) available in each region. It also provides an overview of the existing electricity infrastructures for fossil fuel and renewable sources.

To assess the renewable energy potential based on the area available, all scenario-relevant regions and sub-regions were analysed with the [R]E-SPACE methodology, to quantify the available land area in square kilometres with a defined set of constraints for solar and onshore wind installations:

- Protected areas (PA);
- Areas with steep slope (>30%);
- Certain land-cover classes (e.g. closed forests, wetland, moss and lichen, snow and ice, and water) for both solar and onshore wind, and urban built up land classes for onshore wind.

1.2 MAPPING UKRAINE

Ukraine has large untapped potential for renewable electricity. In 2021, 55% of the Ukraine electricity was generated from nuclear power, followed by 23.2% from coal, 6.3% from gas and 1.1% from other fossil fuels. The remaining 13.9% of power generation are from renewable source of which hydro plays the largest role (6.8%), followed by solar photovoltaics (3.8%), wind (2.9%) and bio energy (0.5%)[12].

1.2.1 NATIONAL SOLAR POTENTIAL -

The average annual solar irradiation (DNI) level in Ukraine is between around 950 and 1500 kWh/m^2 per day, and the higher end of that range is in the southern part of the country.

Ukraine's solar potential has been mapped under two different scenarios.

Scenario 1. Available land—excluding protected areas (PA), extreme topography (slope > 30%, and certain land-cover classes, including closed forests, wetlands, moss and lichen, snow and ice, and water (permanent water bodies) (LU).

Scenario 2. See 1, with additional restriction that excludes areas ≤ 10 km from existing transmission lines (PT10).

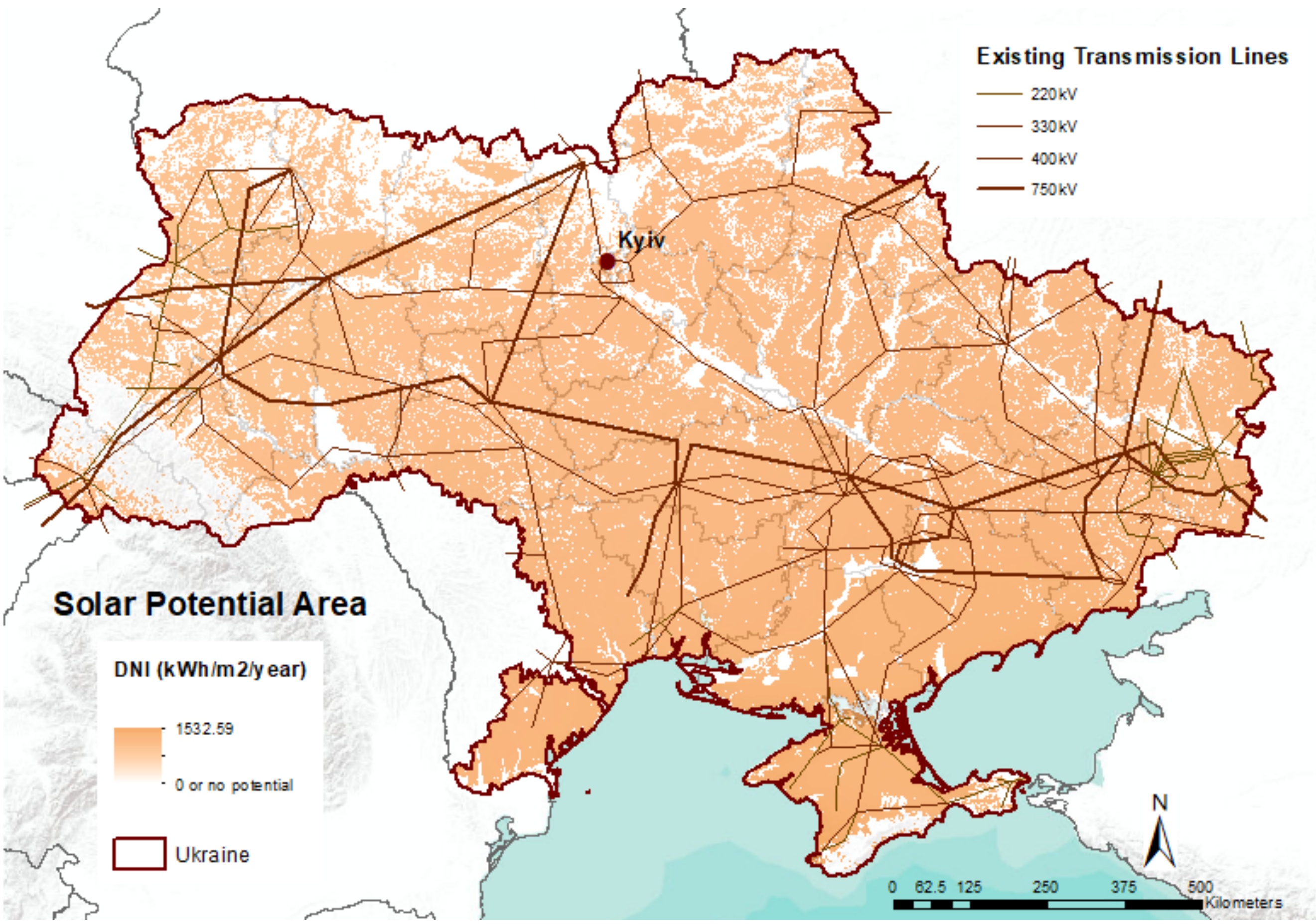


Figure 2: Scenario 1 - solar potential in the Ukraine - land-use restrictions

[12] CSR in energy and agrarian sectors of Ukraine; Associate Prof. of Management and Marketing Department at Ukrainian National Forestry University (Lviv) Andrii Holovko,

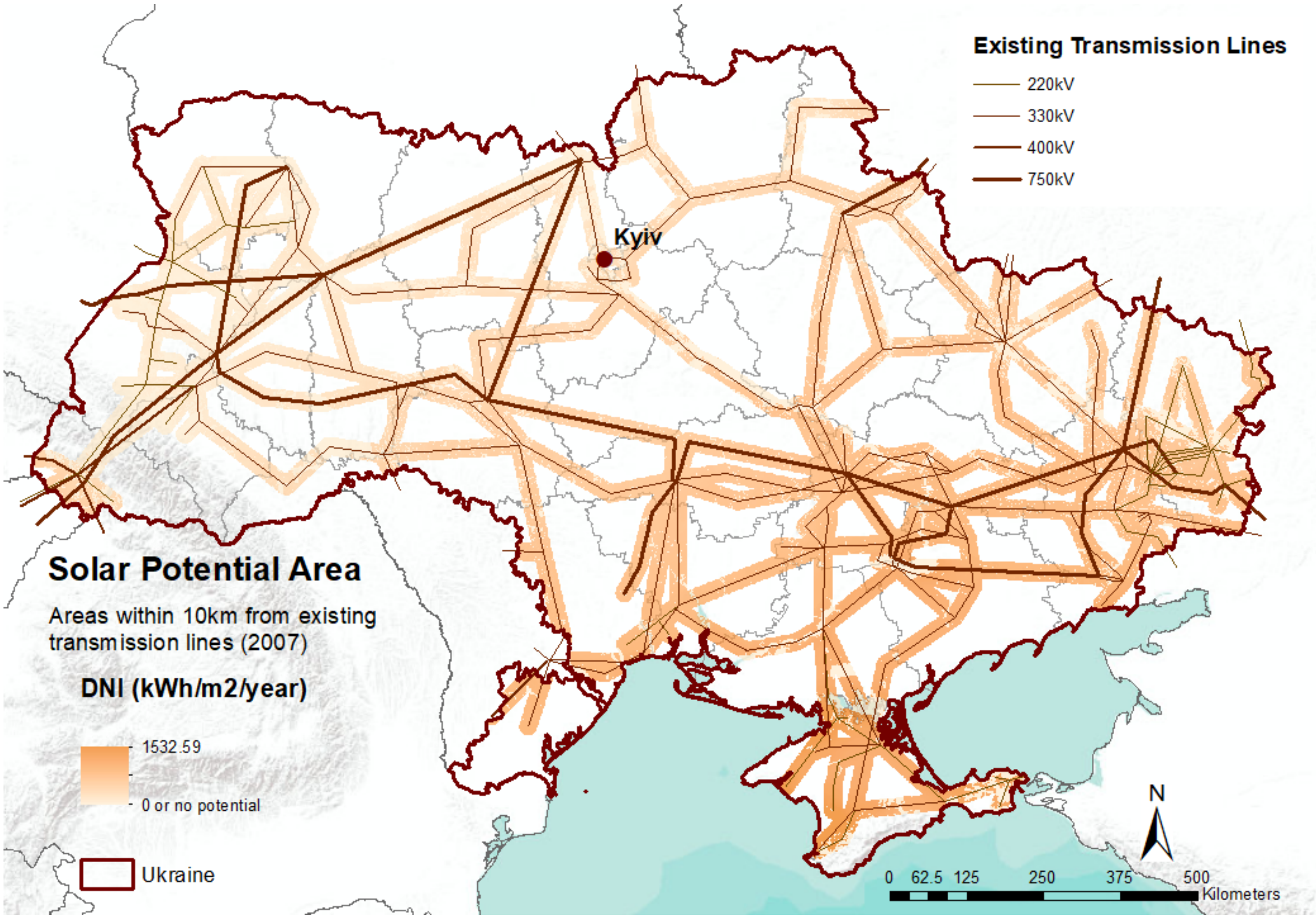


Figure 3: Scenario 2 - solar potential in the Ukraine - Restriction based on proximity to electricity transmission lines

Table 2: Ukraine's potential for solar photovoltaic

	Solar Potential Area (for utility scale)	Solar Potential Installed Capacity	Solar Potential Annual Generation (Capacity Factor 12%)
	[km²]	[GW]	[TWh/a]
Ukraine (with Crimea)			
Scenario 1 - theoretical suitable area	452,042	11,301	11,866
Scenario 2 - grid proximity max 10km	203,379	5,084	5,339

Figure 2 shows the results of a spatial analysis indicating the solar potential areas under Scenario 1 (LU + PA + S30) add up to 452,042 km^2 with a total potential for utility-scale solar PV capacity of 11,301 GW. Scenario 1 excludes all protected areas and areas with slopes > 30%, because installing solar panels in steep areas is costlier and usually distant from electricity demand centres. Open forests, shrubs, herbaceous vegetation, bare/spare vegetation, agricultural land, and urban/built-up land-cover classes in the Copernicus Global Land Cover 2019 dataset (Buchhorn et al., 2020) [13]are included. However, certain land-cover classes (e.g., closed forests, wetlands, water bodies, snow and ice) are excluded in the scenarios selected for the consideration of solar energy potential.

Figure 3 shows the solar potential areas for Scenario 2 (LU + PA + S30 + PT10). When the land area is restricted by its proximity to power lines (10 km), the potential solar areas decrease to 203,379km^2. While this grid proximity restriction leads to a substantial decrease of solar potential, the remaining potential is still significantly over Ukraine's current electricity demand. Under Scenario 2, utility-scale solar farms with a total capacity of 5,084 GW could be installed across the Ukraine, leading to a potential annual electricity generation of over 5,000 TWh. (Table 2). The calculated solar electricity generation is based on the average solar radiation across the entire Ukraine. 1 kilowatt of solar modules installed in the far south of the country

[13] Buchhorn et. al. 2020, Buchhorn, M. ; Lesiv, M. ; Tsendbazar, N. - E. ; Herold, M. ; Bertels, L. ; Smets, B. Copernicus Global Land Cover Layers-Collection 2. Remote Sensing 2020, 12Volume 108, 1044. doi:10.3390/rs12061044

would produce almost 50% more electricity than those installed in the north. However, the technology can be used in all parts of the Ukraine. In fact, solar photovoltaic modules are even used in the Arctic. In 2023, Norway has installed the world's northernmost ground solar panels in its Svalbard archipelago, despite the region being plunged into darkness from early October until mid-February every year[14].

1.2.2 SOLAR POTENTIAL – BY PROVINCE

The national solar potential under both land-use scenarios has been further broken down to the provinces of the Ukraine. Table 3 provides an overview to all suitable areas for utility scale solar photovoltaic and the possible installed capacity by province.

Table 3: Ukraine's solar photovoltaic potential by province

Solar - Scenario 1			Solar - Scenario 2	
Scenario 1 - Ukraine (all)	Area (km2)	Solar Potential (MW)	Area (km2)	Solar Potential (MW)
Autonomous Republic of Crimea	18,942	473,556	12,325	308,134
Cherkaska	16,714	417,852	3,508	87,694
Chernihivska	19,988	499,695	4,259	106,463
Chernivetska	5,276	131,892	1,268	31,702
Dnipropetrovska	28,290	707,250	17,957	448,914
Donetska	23,576	589,408	15,876	396,906
Ivano-Frankivska	6,251	156,277	3,647	91,180
Kharkivska	25,199	629,969	9,098	227,444
Khersonska	21,390	534,753	7,381	184,522
Khmelnytska	15,461	386,534	7,380	184,494
Kirovohradska	22,698	567,444	12,451	311,286
Kyiv	405	10,134	386	9,645
Kyivska	19,016	475,405	6,981	174,514
Luhanska	21,794	544,855	12,975	324,369
Lvivska	12,495	312,375	7,756	193,888
Mykolaivska	22,625	565,622	10,018	250,453
Odeska	29,313	732,833	8,572	214,300
Poltavska	22,350	558,738	7,060	176,511
Rivnenska	10,739	268,478	3,475	86,883
Sevastopol	49	1,233	27	683
Sumska	16,448	411,211	7,503	187,581
Ternopilska	11,045	276,128	5,362	134,052
Vinnytska	23,240	580,994	11,036	275,903
Volynska	11,482	287,038	6,185	154,616
Zakarpatska	3,844	96,106	2,604	65,108
Zaporizka	24,615	615,378	10,903	272,584
Zhytomyrska	18,796	469,891	7,386	184,658
TOTAL	452,042	11,301,047	203,379	5,084,484

[14] Solar panels installed in remote Arctic community to power green energy transition Svalbard archipelago solar panel installation. By Rory Elliott Armstrong & Euronews Green with AFP Published on 19/09/2023, https://www.euronews.com/green/2023/09/19/solar-panels-installed-in-remote-arctic-community-to-power-green-energy-transition

1.2.3 ONSHORE WIND POTENTIAL

The overall wind resources on land are lower in Ukraine compared with the solar potential. The wind speeds in Ukraine range from 1.3 to 12.5m/s at 100 m height (Global Wind Atlas). In this analysis, we have included only areas with an average annual wind speed of ≥ 5 m/s. Ukraine's wind potential has been mapped under two different scenarios. The current use of wind energy in Ukraine involves utility scale wind turbines in the range up to 10 kilowatts, operated both on- and off-grid as battery chargers.

'Scenario 1': Available land—restricted by protected areas (PA), topography (slope > 30%, S30), and existing land use, including forests and urban areas (LU). (Figure 4)

'Scenario 2': See 1, with the additional restriction excluding areas ≤ 10 km from existing transmission lines (PT10) (Figure 5).

Open forest, shrubs, herbaceous vegetation, bare/sparse vegetation, and agricultural land were included in the available land (LU) for the two wind scenarios, whereas the land-cover classes closed forests, wetland, moss and lichen, urban/built up areas, snow and ice, and permanent water bodies were excluded in this analysis of wind potential.

Ukraine's onshore wind potential under the assumptions of *'Scenario 1'* is significant with a theoretical annual wind generation enough to power the current electricity demand of the entire European Union six times over. Figure 4 shows the onshore wind potential in the Ukraine - land-use but no infrastructural restrictions and Figure 5 with the limited potential limited to within the proximity of ≤10km to the transmission grid. Table 4 shows the exact results of both scenario in available area, potentially installed capacity and resulting annual generation with an average annual capacity factor of 35%.

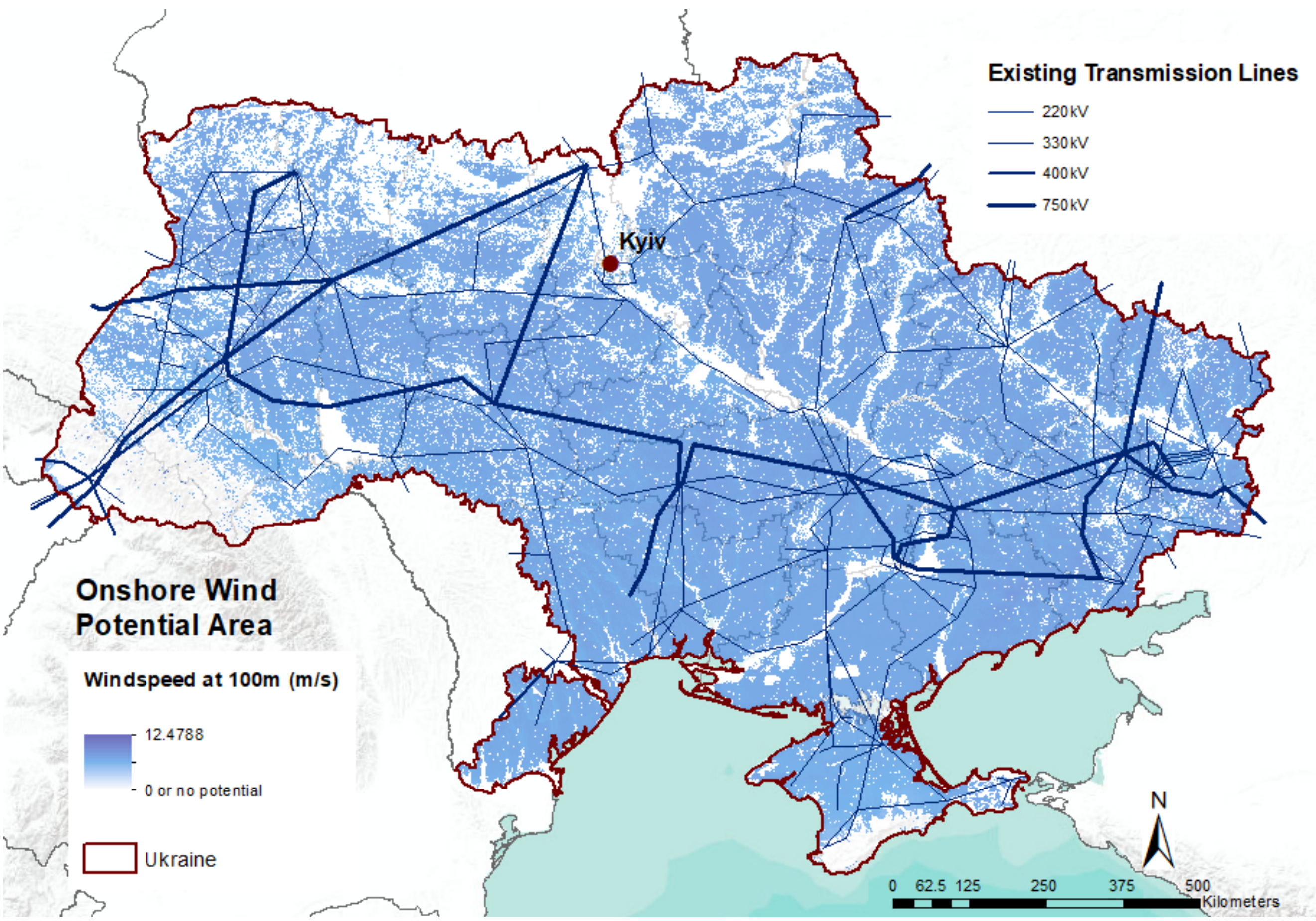


Figure 4: Scenario 1 – onshore wind potential in the Ukraine - land-use but no infrastructural restrictions.

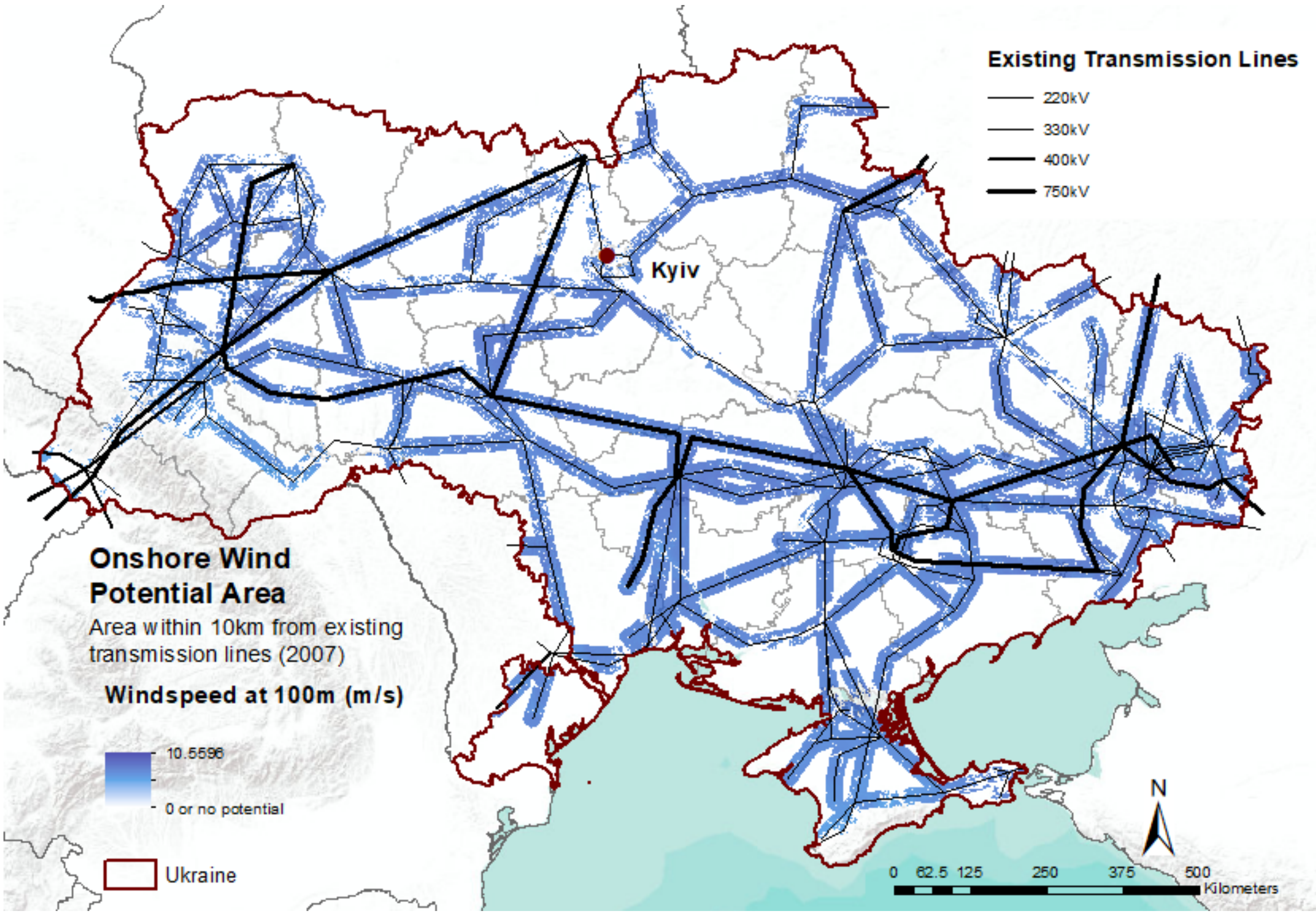


Figure 5: Scenario 2 – onshore wind potential in the Ukraine - Restriction based on proximity to electricity transmission lines

Table 4: Ukraine's potential for onshore wind

	Wind Potential Area (onshore)	Wind Potential Installed Capacity	Wind Potential Annual Generation (Capacity Factor 35%)
	[km^2]	[GW]	[TWh/a]
Ukraine (with Crimea)			
Scenario 1 - theoretical suitable area	429,249	2,146	6,546
Scenario 2 - grid proximity max 10km	189,950	950	2,897

1.2.4 ONSHORE WIND POTENTIAL – BY PROVINCE

Table 5 shows the onshore wind potential by province both in terms of area in square kilometre as well as possible installed capacities.

Table 5: Ukraine's onshore wind potential by province

Onshore Wind - Scenario 1			Onshore Wind - Scenario 2	
Scenario 1 - Ukraine (all)	Area (km2)	Wind Potential (MW)	Area (km2)	Wind Potential (MW)
Autonomous Republic of Crimea	17,524	87,618	11,477	57,383
Cherkaska	15,963	79,815	3,305	16,523
Chernihivska	19,331	96,656	4,060	20,298
Chernivetska	4,677	23,384	1,079	5,393
Dnipropetrovska	26,663	133,314	16,676	83,378
Donetska	21,873	109,363	14,628	73,138
Ivano-Frankivska	5,864	29,318	3,478	17,388
Kharkivska	24,050	120,249	8,329	41,644
Khersonska	20,747	103,737	7,070	35,348
Khmelnytska	14,922	74,609	7,063	35,317
Kirovohradska	22,157	110,786	12,150	60,749
Kyiv	106	531	99	494
Kyivska	17,702	88,510	6,290	31,448
Luhanska	20,614	103,070	12,160	60,802
Lvivska	12,314	61,569	7,332	36,662
Mykolaivska	22,029	110,145	9,741	48,706
Odeska	28,047	140,235	8,090	40,451
Poltavska	21,464	107,321	6,672	33,362
Rivnenska	10,477	52,384	3,319	16,594
Sevastopol	1	4	0	1
Sumska	15,679	78,397	7,193	35,964
Ternopilska	10,637	53,187	5,159	25,796
Vinnytska	22,373	111,867	10,619	53,093
Volynska	11,196	55,979	5,965	29,824
Zakarpatska	841	4,206	524	2,620
Zaporizka	23,775	118,874	10,345	51,727
Zhytomyrska	18,223	91,114	7,130	35,648
TOTAL	429,249	2,146,243	189,950	949,748

2 Ukraine: The energy economic importance of the solar & wind potential

The energy economic importance of Ukraine solar and onshore wind electricity generation potential becomes clear when compared to its domestic electricity demand. Under the assumptions of scenario 1, only 0.46% of the solar and 0.4% of the wind potential would be sufficient to supply the entire country with electricity.

Under the more realistic assumption to utilize only land within a proximity of 10 km from a high voltage line, the Ukraine could generate its final electricity demand (2021) with only 1% of its suitable land area for solar and wind installations.

The Ukraine has an enormous solar and wind energy potential that exceeds current electricity demand (125 TWh/a)– even under conservative land-use restriction – close to 150 times over. Thus, only a small percentage of the theoretical suitable land for utility solar and onshore wind is required to supply the entire country with electricity.

Even under the assumption, that a future full decarbonization of Ukraine's energy supply will triple or even quadruple due to increased electrification of the transport sector, residential space heating with heat pumps and industrial process heating via synthetic fuels such as hydrogen and ammonia as well as industrial scale heat pumps, the renewable electricity potential does not provide any limitations. Furthermore, besides solar and onshore wind, the Ukraine can utilize offshore wind, bio energy, geothermal energy and hydro power. However, the potential analysis for those sources were out of scope for this research.

Table 6: Ukraine – solar and wind potential in comparison to domestic demand

Ukraine (with Crimea) Electricity demand in 2021: 125 TWh/a	Solar Potential Installed Capacity	Solar Potential Annual Generation (Capacity Factor 12%)	Wind Potential Installed Capacity	Wind Potential Annual Generation (Capacity Factor 35%)	Solar + Wind Potential Installed Capacity	Solar + Wind Potential Annual Generation	Supply Factor (Solar + Wind)
	[GW]	[TWh/a]	[GW]	[TWh/a]	[GW]	[TWh/a]	[1]
Scenario 1 - theoretical suitable area	11,301	11,866	2,146	6,546	13,447	18,460	148
Scenario 2 - grid proximity 10km	5,084	5,339	950	2,897	6,034	8,257	66

2.1 RENEWABLE ENERGY EXPORT POTENTIAL

Ukraine's significant solar and onshore wind resources cannot only be utilized for domestic supply, but also for energy exports to the neighbouring countries. The energy can be exported either in form of electricity via power grid, or in form of hydrogen, synthetic fuels – produced with renewable electricity – via pipeline or tanker over land or sea.

To put Ukraine's solar and onshore wind potential into a global perspective, the results are compared with renewable energy potentials for all G20 countries which served as a basis for 1.5˚C Paris aligned decarbonization pathways, a research project for the United Nations Finance Initiative and the UN-convened Net Zero Asset Owners Alliance undertaken in 2023 (Teske et. al. 2023)[15].

2.1.1 AVAILABLE LAND AREA FOR SOLAR AND WIND GENERATION – UKRAINE AND G20

Table 7 shows the available land area for solar and onshore wind in the Ukraine and G20 under the assumptions and calculated with the methodology documented in section 1.1. Please note that the areas for suitable for solar and wind cannot add up, as they are overlapping and it would lead to double counting of land.

In comparison with the member countries of the European Union (EU27), both Ukraine's solar as well as onshore wind resources are almost equal as those of Germany, France and Italy combined.

These resources can contribute to Europeans energy security and help to decarbonize EU's economy faster.

[15] Teske et. al. 2023, Teske, S., Rispler, J., Niklas, S. et al. Net-zero 1.5 °C sectorial pathways for G20 countries: energy and emissions data to inform science-based decarbonization targets. SN Appl. Sci. 5, 252 (2023). https://doi.org/10.1007/s42452-023-05481-x

Table 7: Ukraine – solar and wind potential in comparison to G20 countries – land-area

	Country Area [km²]	Solar Potential Area [km²]	Share of land area suitable for utility scale solar wind	Area Onshore Wind Potential [km²]	Share of land area suitable for Onshore wind
Ukraine (with Crimea)	599,895				
Scenario 1 - theoretical suitable area		452,042	75%	429,249	72%
Scenario 2 - grid proximity max 10km		203,379	34%	189,950	32%
Europe					
EU27 Total	4,119,785	1,376,011	33%	1,326,087	32%
France (G20 & G7)	549,048	265,645	48%	249,782	45%
Germany (G20 & G7)	357,625	57,852	16%	139,767	39%
Italy (G20 & G7)	300,769	158,780	53%	49,812	17%
United Kingdom (G20 & G7)	244,928	1,134	0%	119,854	49%
Russia	16,930,400	2,667,510	16%	4,643,550	27%
Africa & Middle East					
Saudi Arabia (G20)	1,924,460	1,682,780	87%	1,619,240	84%
South Africa (G20)	1,219,870	959,713	79%	793,516	65%
Americas					
Canada (G7 & G20)	9,963,910	2,095,810	21%	3,350,930	34%
United States of America (G7 & G20)	9,473,400	4,810,580	51%	4,351,580	46%
Mexico (G20)	1,956,390	1,160,220	59%	491,606	25%
Brazil (G20)	8,471,710	3,494,390	41%	1,682,680	20%
Argentina (G20)	2,779,060	1,797,550	65%	1,932,520	70%
Asia & Australia					
Turkey (G20)	780,528	527,680	68%	229,396	29%
South Korea (G20)	98,801	32,823	33%	10,620	11%
China (G20)	9,345,830	5,151,340	55%	4,793,340	51%
India (G20)	3,150,160	2,839,050	76%	886,384	28%
Indonesia (G20) (IESR)	1,883,260	277,007	12%	24,890	1%
Japan (G7 & G20)	376,487	60,837	16%	21,340	6%
Australia (G20)	7,685,420	5,140,920	67%	4,850,800	63%
Total G7 (excluding EU27)	21,266,167	7,450,638	35%	8,283,065	39%
Total G20 (excluding EU27)	60,561,656	30,014,111	50%	25,598,056	42%

The GIS based solar and wind potential analysed is published as open source data under www.uts.edu.au/oecm

Based on the suitable land-area, the potential installed capacities and possible electricity generation per year has been calculated (Miyake, 2023)[16]. For utility scale solar, it is assumed that on each square kilometre a capacity of 25 MW solar photovoltaic modules with an average efficiency of 18% can be installed. Higher efficiencies would decrease the amount of space for each MW further. Furthermore, space for access roads and working lanes are included and therefore not the entire land-area can be used for solar modules. In case of agricultural solar pv project, the modules are installed high above the ground and the same space can be used for food production and/or other crops for bioenergy or bio material production.

For onshore wind, it is assumed that 2 MW to 3 MW turbines are installed and that the distance between wind generators is around 6 to 7 times the rotor diameter. A standard three-blade, upwind, horizontal axis 3 MW wind turbines has an average rotor diameter of 115m to 140m (depending on the model and if those are coastal or inland optimized machines). Thus, the average installed capacity per square kilometre is assumed with 5 MW. Utility scale solar and wind turbines can be combined on the same land. However, due to the vast potential, solar and wind projects might usually not be on the same block of land.

[16] Miyake 2023, https://mangomap.com/university-of-technology-sydney/maps/132307/solar-potential-area-in-g20?preview=true# and https://www.uts.edu.au/oecm/renewable-resource-mapping

Table 8 shows the solar and onshore wind potential of all G20, both in regard of the installed capacity in *Gigawatt* [GW] as well as the expected average annual generation in *Terawatt hours per year* [TWh/a]

Table 8: Ukraine – solar and wind potential in comparison to G20 countries – energy units

	Solar Potential Installed Capacity	Solar Potential Annual Generation (Capacity Factor 12%)	Wind Potential Installed Capacity	Wind Potential Annual Generation (Capacity Factor 35%)	Solar + Wind Potential Installed Capacity	Solar + Wind Potential Annual Generation	Current electricity demand
	[GW]	[TWh/a]	[GW]	[TWh/a]	[GW]	[TWh/a]	[TWh/a]
Ukraine (with Crimea)		1,051		3,066			125
Scenario 1 - theoretical suitable area	11,301	11,880	2,146	6,580	13,447	18,460	
Scenario 2 - grid proximity max 10km	5,084	5,345	950	2,912	6,034	8,257	
Europe							
EU27 Total	34,400	36,162	6,630	20,329	41,031	56,490	2,564
France (G20 & G7)	6,641	6,981	1,249	3,829	7,890	10,810	444
Germany (G20 & G7)	1,446	1,520	699	2,143	2,145	3,663	527
Italy (G20 & G7)	3,970	4,173	249	764	4,219	4,936	281
United Kingdom (G20 & G7)	28.3485	29.7999432	599.27	1837.36182	627.6185	1,867	283
Russia	66,688	70,102	23,218	71,186	89,906	141,288	749
Africa & Middle East							
Saudi Arabia (G20)	42,070	44,223	8,096	24,823	50,166	69,046	347
South Africa (G20)	23,993	25,221	3,968	12,165	27,960	37,386	189
Americas							
Canada (G7 & G20)	52,395	55,078	16,755	51,370	69,150	106,448	528
United States of America (G7 & G20)	120,265	126,422	21,758	66,710	142,022	193,132	3,844
Mexico (G20)	29,006	30,491	2,458	7,536	31,464	38,027	266
Brazil (G20)	87,360	91,833	8,413	25,795	95,773	117,628	537
Argentina (G20)	44,939	47,240	9,663	29,626	54,601	76,865	123
Asia & Australia							
Turkey (G20)	13,192	13,867	1,147	3,517	14,339	17,384	260
South Korea (G20)	821	863	53	163	874	1,025	502
China (G20)	128,784	135,377	23,967	73,482	152,750	208,859	6,198
India (G20)	59,726	62,784	4,432	13,588	64,158	76,373	1,255
Indonesia (G20) (IESR)	5,675	5,966	124	382	5,800	6,347	289
Japan (G7 & G20)	1,521	1,599	107	327	1,628	1,926	898
Australia (G20)	128,523	135,103	24,254	74,363	152,777	209,466	212
Total G7 (excluding EU27)	186,266	195,803	41,415	126,979	227,681	322,782	6,805
Total G20 (excluding EU27)	750,353	788,771	127,990	392,418	878,343	1,181,189	16,983

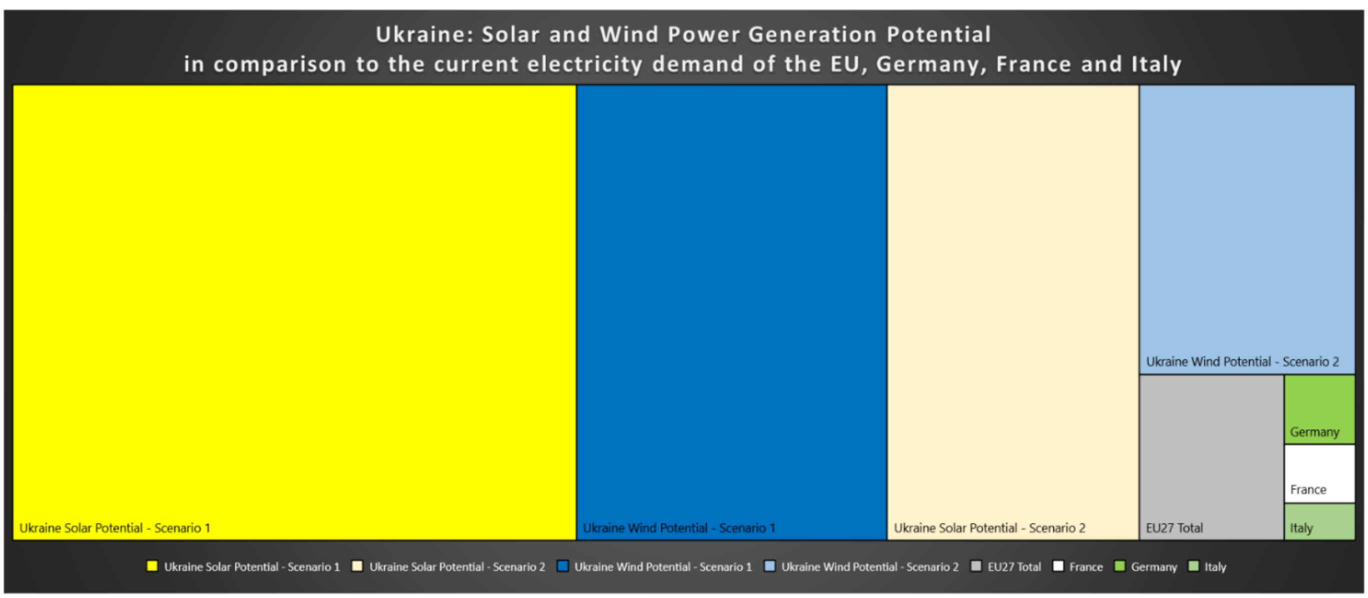


Figure 6: Ukraine – solar and wind power generation potential in comparison to EU countries

2.1.2 INFRASTRUCTURE FOR ENERGY EXPORTS

Exporting renewable electricity or renewable-energy based gases and fuels requires dedicated energy infrastructure – designed for export. The capacity of high voltage power lines must be significantly larger than those designed for limited electricity trading with neighbouring countries.

The Ukraine currently has power grid connections with four EU member countries – Poland, Slovak Republic, Hungary and Romania – which can be utilized to import renewable electricity into EU. Figure 7 shows Interconnectors and electricity grids between the Ukraine and its neighbouring countries. The map is taken from a publication of the German Institute for International and Security Affairs (SWP 2021) [17]

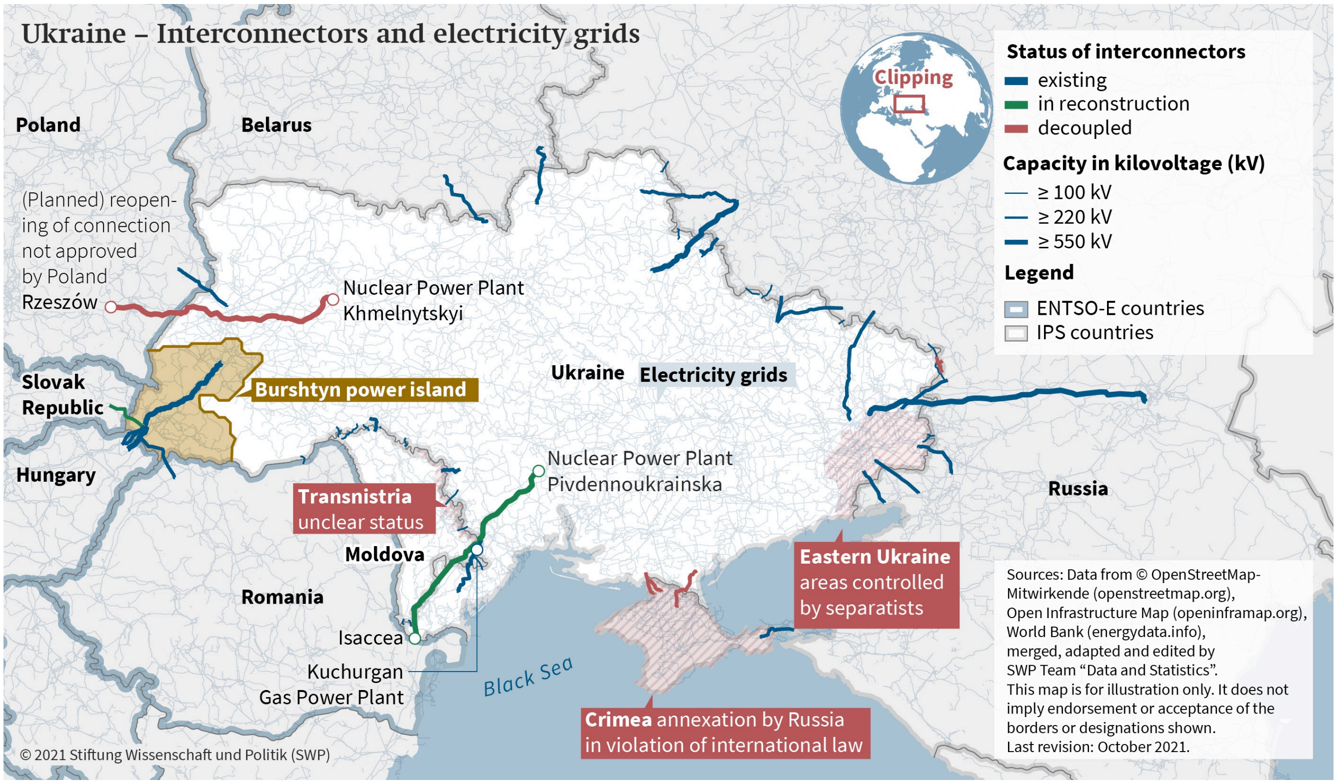


Figure 7: Ukraine – Interconnectors and electricity grids – German Institute for International and Security Affairs, SWP 2021

'Connecting Ukraine to the continental European power grid and the EU's electricity market is on the political agenda. However, establishing the necessary grid connections is technically complicated and also requires profound reforms to the Ukrainian electricity sector. But it is not only Ukraine that has to deliver; the EU and its member states will also have to make far-reaching and hugely significant geopolitical decisions. The project needs a politically coordinated roadmap that defines clear criteria and conditions for a common electricity grid' (SWP 2021)[18].

The 'Joint Statement of the United States and Germany on Support for Ukraine, European Energy Security, and our Climate Goals' released on the 21st July 2021 from the U.S. Department of State, identifies Europe's energy supply and its reliance from non-EU member countries as a major issue for future political discussions. The declaration states '

'Should Russia attempt to use energy as a weapon or commit further aggressive acts against Ukraine, Germany will take action at the national level and press for effective measures at the European level, including sanctions, to limit Russian export capabilities to Europe in the energy sector, including gas, and/or in other economically relevant sectors.'

[17] Connecting Ukraine to Europe's Electricity Grid, Technical Details and Hard Geopolitics, Lukas Feldhaus, Kirsten Westphal, Georg Zachmann, SWP Comment 2021/C 57, 24.11.2021, 8 Seiten, doi:10.18449/2021C57

[18] SWP 2021, Connecting Ukraine to Europe's Electricity Grid, Technical Details and Hard Geopolitics, Lukas Feldhaus, Kirsten Westphal, Georg Zachmann, SWP Comment 2021/C 57, 24.11.2021, 8 Seiten, doi:10.18449/2021C57

Green Rebuild – Decarbonization of the economy with Renewable energy and energy efficiency as a corner stone

The joined declaration of the USA and Germany identified energy infrastructure projects such as grid interconnections, renewable energy and energy efficiency projects as cornerstones for a future '*Green Rebuild*'. Below, the most important extracts from the declaration:

- *The United States and Germany are resolute in their commitment to the fight against climate change and ensuring the success of the Paris Agreement by reducing our own emissions in line with net-zero by 2050 at the latest, encouraging the strengthening of climate ambition of other major economies, and collaborating on the policies and technologies to accelerate the global net-zero transition. (…)*
- *The Partnership will foster U.S.-Germany collaboration on developing actionable roadmaps to reach our ambitious emission reduction targets; coordinating our domestic policies and priorities in sectoral decarbonization initiatives and multilateral fora; mobilizing investment in energy transition; and developing, demonstrating, and scaling critical energy technologies such as renewable energy and storage, hydrogen, energy efficiency, and electric mobility.*
- *As part of the U.S.-Germany Climate and Energy Partnership, we have decided to establish a pillar to support the energy transitions in emerging economies. This pillar will include a focus on supporting Ukraine and other countries in Central and Eastern Europe. These efforts will not only contribute to the fight against climate change but will support European energy security by reducing demand for Russian energy.*
- *In line with these efforts, Germany commits to establish and administer a Green Fund for Ukraine to support Ukraine's energy transition, energy efficiency, and energy security.*
- *Germany and the United States will endeavour to promote and support investments of at least $1 billion in the Green Fund for Ukraine, including from third parties such as private-sector entities.*
- *Germany will provide an initial donation to the fund of at least $175 million and will work toward extending its commitments in the coming budget years. The fund will promote the use of renewable energy; facilitate the development of hydrogen; increase energy efficiency; accelerate the transition from coal; and foster carbon neutrality.*
- *The United States plans to support the initiative via technical assistance and policy support consistent with the objectives of the fund, in addition to programs supporting market integration, regulatory reform, and renewables development in Ukraine's energy sector.*
- *In addition, Germany will continue to support bilateral energy projects with Ukraine, especially in the field of renewables and energy efficiency, as well as coal transition support, including the appointment of a special envoy with dedicated funding of $70 million.*
- *Germany is also ready to launch a Ukraine Resilience Package to support Ukraine's energy security. This will include efforts to safeguard and increase the capacity for reverse flows of gas to Ukraine, with the aim of shielding Ukraine completely from potential future attempts by Russia to cut gas supplies to the country.*
- *It will also <u>include technical assistance for Ukraine's integration into the European electricity grid</u>, building on and in coordination with the ongoing work by the EU and the U.S. Agency for International Development. In addition, Germany will facilitate Ukraine's inclusion in Germany's Cyber Capacity Building Facility, support efforts to reform Ukraine's energy sector, and assist with identifying options to modernize Ukraine's gas transmission systems.*

To conclude section 2 of the UTS renewable energy assessment:

The vast solar and wind energy potentials of the Ukraine can and should be utilized for a Green Rebuild of the Ukraine for a resilient and carbon-free economy and to support EU member states with the supply of renewable energy.

3 Ukraine: Benefits of renewable energy exports

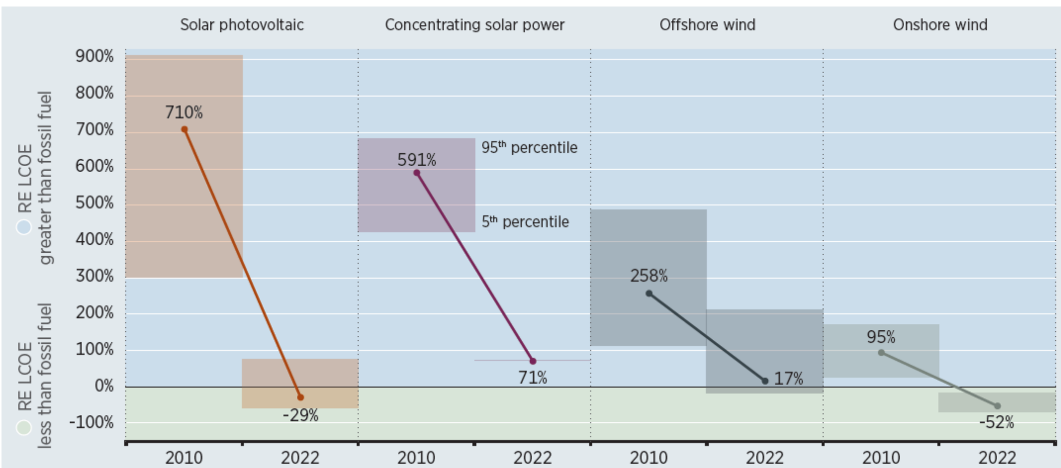
The utilization of renewable energies has many benefits both for the Ukraine, but also for its neighbouring EU member states.

3.1 RENEWABLE POWER GENERATION –ECONOMIC ADVANTAGES

Renewable energies decarbonize the energy sector, solar and wind have no fuel needs and therefore generation costs are reliable and stable with no exposure to international fuels price fluctuation. Renewable power generation is now the most economic form of electricity supply. The international Renewable Energy Agency (IRENA) stated in its annual flagship publication 'Renewable Power Generation Costs in 2022' that the competitiveness of renewables continued to improve despite rising materials and equipment costs in 2022 (IRENA 2023)[19].

'The economic benefits of solar and wind technologies – in addition to their environmental benefits – are now compelling. Owing to soaring fossil fuel prices, the 2021-2022 period saw one of the largest improvements in the competitiveness of renewable power in the last two decades.' IRENA, Renewable Power Generation Costs in 2022 (23 August 2023)

Generation costs for solar and wind power generation have fallen constantly over more than a decade. In 2010 solar photovoltaic power generation was 710% more expensive than the average fossil fuel-based electricity, in 2022 solar electricity was 29% cheaper. Onshore wind decreased from 95% more expensive in 2010 to 52% cheaper than the average coal and gas-based power generation (Figure 8).



Note: The global weighted average LCOE data by technology and the fossil fuel LCOE data used to derive this chart is presented in detail in Chapter 1; RE = renewable energy.

Figure 8: Change in competitiveness of solar and wind by country based on global weighted average LCOE,2010-2022, IRENA 2023

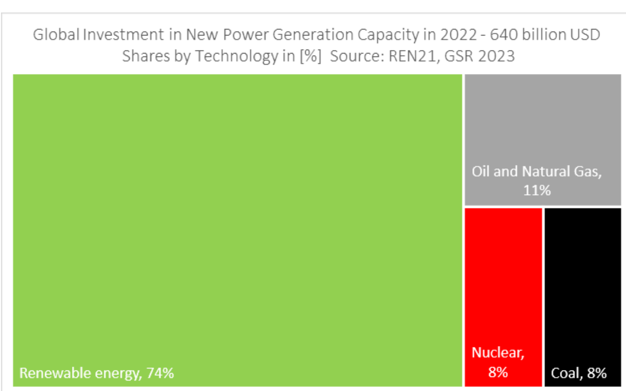


Figure 9: Global Investment in New Power Capacity, by Type, 2022, REN21, GSR 2023

Due to the significant economic advantages, of renewable power generation, 74% of the total investment of USD 640 billion in new power plants went to renewable in 2022 (REN21 2023)[20].

Renewable power technologies dominating the new investment market for more than five consecutive years.

[19] IRENA 2023, RENA (2023), Renewable power generation costs in 2022, International Renewable Energy Agency, Abu Dhabi. ISBN 978-92-9260-544-5
[20] REN21, 2023, RENEWABLES 2023, GLOBAL STATUS REPORT https://www.ren21.net/gsr-2023/

3.2 RENEWABLE ENERGY - EMPLOYMENT POTENTIAL

Finally, renewable energies provide long-term job opportunities. According to the International Renewable Energy Agency (IRENA), the renewable energy industry provides 13.7 million globally in 2023, 1 million more than in 2022.

About 4.9 million jobs were in the solar photovoltaic industry, followed by around 2.5 million jobs both in the hydro power and bio fuels industry and 1.4 million jobs in the wind industry (IRENA 2023B[21]).

In order to estimate the approximate job potential, a very simple market development scenario for the Ukrainian solar and wind industry was adopted:

It was assumed that by 2030 the market for new installed solar and wind systems would be back to the level of 2021 and then increase continuously over the next 20 years with robust annual market growth. The annual new installed solar and wind capacities are multiplied with average industry-standard employment factors (Table 9).

Table 9: Average employment factors for the solar photovoltaic and wind energy industry (UTS/ISF)

	Construction/ installation	Manufacturing	Operations & maintenance
	Job years/ MW	Job years/ MW	Jobs/MW
Photovoltaic	3.2	1.5	0.7
Wind onshore	3.0	3.4	0.3
Wind offshore	6.5	13.6	0.15

Table 10 shows the simplified employment potential estimation and the assumed solar and wind market development. This calculation is strictly indicative, and a more detailed energy scenario development and industry assessment is required.

Table 10: Green Rebuild – Solar and Wind development scenario

					Projection >>>									
Ukraine	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2035	2040	2050
Cumulative Installed capacity in [MW]														
Solar PV	6,075	6,381	6,381	6,381	6,681	7,026	7,440	7,947	8,622	9,532	10,762	20,452	36,275	102,798
Onshore wind	1,314	1,672	1,672	1,672	1,872	2,092	2,340	2,624	2,959	3,377	3,889	8,168	15,177	44,646
Annual Installed Capacity in [MW/a]														
Solar PV	1,239	1,301	0	0	300	345	414	507	675	911	1,229	2,356	3,795	9,842
Onshore wind	358	456	0	0	200	220	248	285	334	418	512	1,044	1,681	4,360
Annual Growth Rate in [%/a]														
Solar PV	25.6%	5.0%	0.0%	0.0%	10.0%	15.0%	20.0%	22.5%	33.0%	35.0%	35.0%	10.0%	10.0%	10.0%
Onshore wind	12.3%	27.2%	0.0%	0.0%	10.0%	10.0%	12.5%	15.0%	17.5%	25.0%	22.5%	10.0%	10.0%	10.0%
Implemented share of Potential 'Scenario 2' - [%]														
Solar PV	0.12%	0.13%	0.13%	0.13%	0.13%	0.14%	0.15%	0.16%	0.17%	0.19%	0.21%	0.40%	0.71%	2.02%
Onshore wind	0.14%	0.18%	0.18%	0.18%	0.20%	0.22%	0.25%	0.28%	0.31%	0.36%	0.41%	0.86%	1.60%	4.70%
Extrapolated employment potential in [Job years]														
Solar PV	10,076	10,583	4,467	4,467	6,087	6,540	7,154	7,947	9,205	10,952	13,311	25,390	43,227	118,216
Onshore wind	2,685	3,417	502	502	1,842	2,036	2,286	2,609	3,028	3,688	4,444	9,130	15,311	41,297
Solar & Wind Jobs - total	**12,761**	**14,000**	**4,968**	**4,968**	**7,928**	**8,575**	**9,440**	**10,555**	**12,233**	**14,641**	**17,755**	**34,520**	**58,538**	**159,513**

[21] IRENA 2023B, IRENA and ILO (2023), Renewable energy and jobs: Annual review 2023, International Renewable Energy Agency, Abu Dhabi and International Labour Organization, Geneva, ISBN: 978-92-9260-552-0,

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