System Flexibility Assessment for RES Penetration in Ukraine

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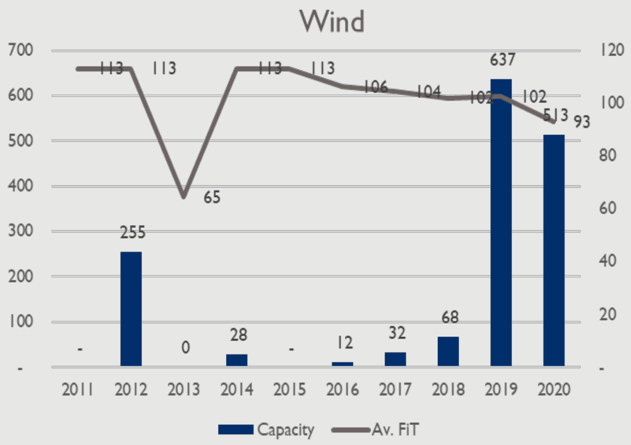
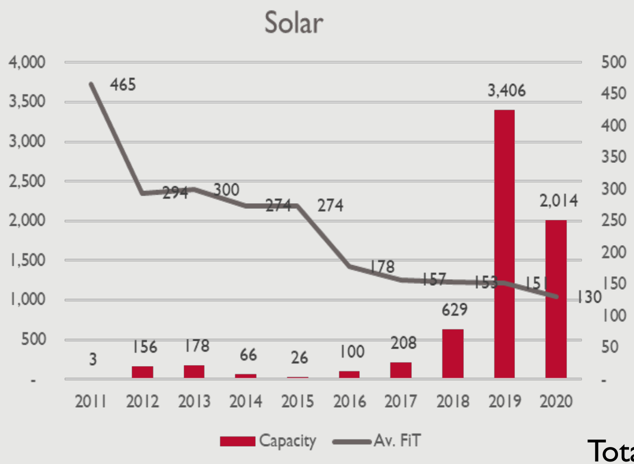
Background of the Study

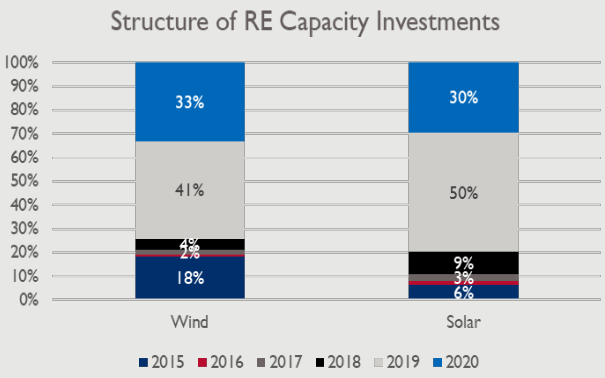
- Generous feed-in-tariffs for renewables led to massive solar and wind penetration in recent years, increasing the stress on the power system operation.
- Financial aspect of the RES support mechanism aside, energy generated by RES plants can exceed the demand cleared on DAM while creating challenges for system operation by the TSO (Ukrenergo).
- ESP delivered the first system flexibility analysis to the TSO in December 2019, the study was advanced recently scope as RES penetration has increased rapidly and now decision makers are at the stage of deciding on investments to increase system flexibility. A more comprehensive analysis with a horizon to 2032 will follow as part of the recently started Network Development Plan (NDP) project for Ukrenergo.
- Challenges addressed in this study:
  - Excessive hourly deviations that cannot be balanced sufficiently quickly
  - Excess power in cases of low consumption and high RES
  - Lack of power in cases of high consumption and low RES
- Question to answer: **Does the current generation mix allow for the integration of a higher share of fluctuating renewable power sources and which balancing options are appropriate?**

FIT Program Capacity Development

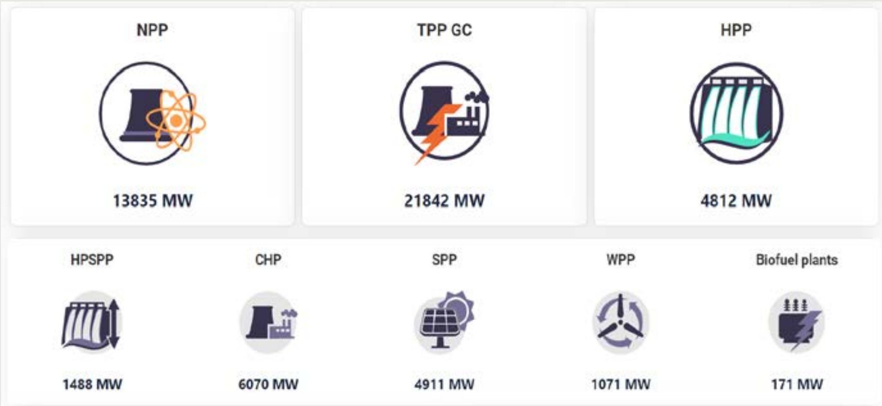




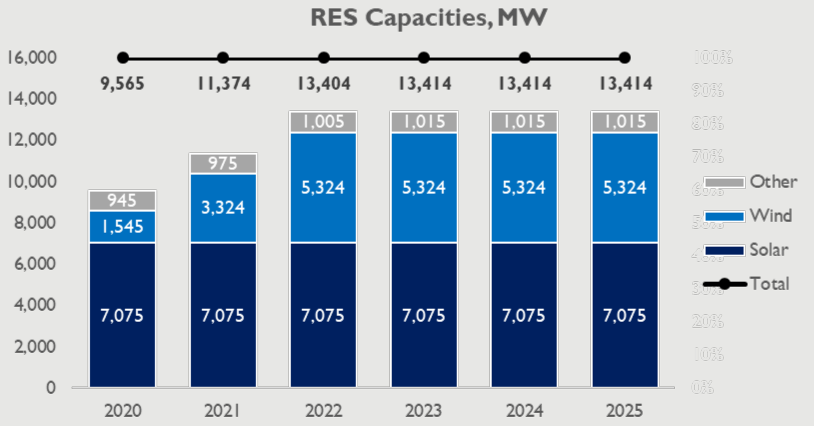
Rapid increase in 2019 and 2020

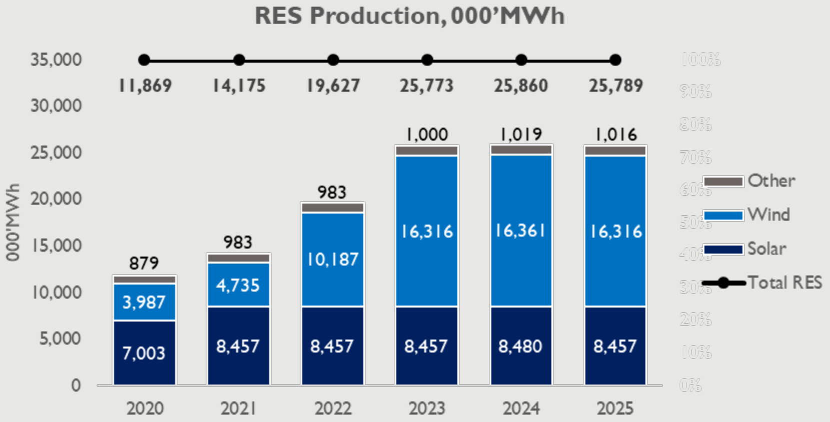


Total Installed Capacity – 31.8.2020



Projection of RES Capacity and Production





Assumptions for the duration of FIT period

1. Solar - No new capacity after 2020
2. Wind – 2,000 MW in 2021 and 2,000 MW in 2022.
3. Auctions – not considered
4. Rooftops excluded in the analysis

High Level Technical Methodology - I

Different approaches are mentioned in the literature and best practices for flexibility adequacy studies*.

- Tier 1: Tools with light data requirements, e. g., no time series. These can be based on data about the generation portfolio, interconnections and other potential sources of flexibility and usually require expert judgement.
- **Tier 2: Tools that calculate sufficiency of flexibility based on time series and more detailed generation data or based on a non-optimal dispatch, typically with calculations performed on a spreadsheet without full optimization.**
- Tier 3: Tools based on optimal dispatch and unit commitment models, combined with generation planning models. Generally, complex solvers are used, and comprehensive economic modelling is required.

**IRENA, 2017, Power System Flexibility for The Energy Transition*

High Level Technical Methodology - II

- This study uses Tier-2 approach with an objective function of **maximization of flexibility** while Tier-3 approach is to be performed as part of "**Network Development Plan**" project that ESP recently started with Ukrenergo

In this context, the methodology to be used in this study is based on two main pillars:

1. **Residual Load Analyses (per ENTSO-E parameters):** The main objective is to identify potential lack of flexible generation in future power system operations of Ukraine. It mainly considers the hourly time-series calculation of residual load and RES ramps and check the system behaviour.

2. **Assessment of Ramping Needs and Sources for Ukraine (Calculating selected EPRI Flexibility Metrics):** As the hourly changes must be met by the dispatchable generations; hourly comparison of flexibility requirements and flexibility resources (hydro, pump-storage, thermal) are applied for both directions; namely downward and upward ramps. Metrics including EUR (Expected Unserved Ramping) and PFD (Period of Flexibility Deficit) are calculated and heuristic limits considering the power system, available reserve capacities and interconnections are applied.

High Level Technical Methodology - III

Criteria#1.1: Residual load is non-zero for all hours

(100% - Residual Load Ratio (%)(t)) < 100%:

Although & it's not a very strict criteria; if the probability of occurrence is high & the RES penetration level should be questionable (low level of flexible dispatchable generation)

Criteria-1.2: RES ramps are below 10% of the load for all hours

RES ramps exceeding 10% of the load are in potential risk because they might be affected by insufficient flexible capacities. This threshold is set as a preliminary value per ENTSO-E practice & but this requires further detailed assessment and historical back testing.

Criteria#2.1: Expected Unserved Downward Ramping is lower than 1% of the load for 99% of the hours (in case of online flexibility).

EUR - Expected Unserved Ramping Downward (t) = (Flexibility Requirement Downward (t): $\Delta RL_{downward}(t)$) - Flexibility Resources Downward (t)

Criteria#2.2: Expected Unserved Upward Ramping is lower than 1% of the load for 99% of the hours (in case of online flexibility).

EUR - Expected Unserved Ramping Upward (t) = (Flexibility Requirement Upward (t): $\Delta RL_{upward}(t)$) - Flexibility Resources Upward (t)

Scenarios - I

Scenarios have been developed for;

- Years of **2021** and **2025**
- Different levels of WPP & SPP penetration (installed capacity)
  - For 2021 Scenarios: WPP: **1,500MW** – **2,600MW,** SPP**: 5,000MW** – **8,000MW**
  - For 2025 Scenarios: WPP: **2,500MW** – **5,000MW**, SPP: **5,000MW – 13,000MW**
- Annual load growth rates: **No growth**, **0.5**% and **1.2% annual increase of demand**
- Mode of operation of the power system
  - Interconnections available
  - Isolated mode of operation

Simulation results were impacted by three assumption groupings: Future uncertainty, data quality and the need for simplification.

Scenarios - II

Baseline scenarios for 2021 and 2025 are selected as follows:

- 2021-Baseline Scenario (RES capacity that Ukrenergo expects to be connected by the year-end):
  - o Installed Capacity of **WPP: 2,585 MW, Installed Capacity of SPP: 6,241 MW**
  - o Yearly Load Growth Rate: **0.5%**
  - o Mode of Operation: **Interconnected**

- 2025-Baseline Scenario-1 (Base scenario in Ukrenergo's Generation Adequacy Study):
  - o Installed Capacity of WPP: **3,000 MW,** Installed Capacity of **SPP: 9,500 MW**
  - o Yearly Load Growth Rate: **1.2%**
  - o Mode of Operation: **Interconnected**
- 2025-Baseline Scenario-2 (Base scenario in Ukrenergo's Generation Adequacy Study):
  - o Installed Capacity of WPP: **3,000 MW,** Installed Capacity of SPP: **9,500 MW**
  - o Yearly Load Growth Rate: **1.2%**
  - o Mode of Operation: **Isolated mode** of operation

Model Validation

For the sake of assessing the accuracy of the technical model that ESP/Mercados has developed for Flexibility Assessment, last 12 months (12 May 2019 – 11 May 2020) were analyzed as well.

- Final Installed Capacity of SPPs (as of May 2020) = 4231MW
- Final Installed Capacity of WPPs (as of May 2020) = 1030MW
- Load and generation dispatches of must-run units are assumed to be as given in the data.
- Hours with RES curtailment has been identified from Ukrenergo's declaration and the restrictions have been reverted (i.e. assumed that RES units have produced in their normal pattern. The objective is to test the model's accuracy for identification of RES curtailment needs)

Results for Validation

Criteria 1.1: RL (Residual Load) magnitude should be non-negative for all hours.	
Number of hours in violation	% of hours in violation
0	0.00%

Criteria-1.2: RES ramps should be below ±10% of the load for all hours	
Number of hours in violation	% of hours in violation
0	0.00%

Criteria#2.1: Downward ramping deficit should be lower than 2.5% of the load for 99% of the hours			
Number of hours in violation	% of hours in violation	Annual Downward Ramping Deficit (MWh)	Downward Ramping Deficit in % of annual RES generation
35	0.40%	34,066	0.56%

~34GWh of RES curtailment need is identified (35 hours)

231 MW of additional maneuvering capacity required to avoid RES restrictions (1.8% capacity factor)

Criteria#2.2: Upward ramping deficit should be lower than 2.5% of the load for 99% of the hours			
Number of hours in violation	% of hours in violation	Upward Downward Ramping Deficit (MWh)	Upward Ramping Deficit in % of annual RES generation
4	0.05%	4,022	0.07%

Actual System Operation Results

Date	Time	Power
5 November 2019	41 min	395 MW
22 December 2019	60 min	350 MW
7 January 2020	70 min	929 MW
14 March 2020	20 min	282.5 MW
15 March 2020	80 min	460 MW
26 March 2020	120-170 min	407 MW
28 March 2020	60 min	409 MW
2 April 2020	48 min	390.4 MW
3 April 2020	180 min	597.6 MW
4 April 2020	>6 h	1363,4 MW
5 April 2020	>5 h	1656,7 MW

~22,6 GWh of RES curtailment need is identified (23 hours)

Main Findings

Scenario Definitions								Results					
Year	Yearly Load Growth	Mode of Operation	RES Penetration Levels		Tertiary System Reserves (MW)		Reduction of Nuclear Gen.	# of Hours with Negative Residual Load	# of hours with RES Ramp Beyond ±10% of Load	Violation # of hours & Downward Ramping Deficit (MWh)	Violation # of hours & Upward Ramping Deficit (MWh)	Additional Maneuvering Capacity Required (MW) (Max)	Capacity Factor for New Generation
			WPP (MW)	SPP (MW)	95% of all hours	Min. of all hours							
2021	0.5%	Intercon	**2,585**	**6,241**	1000	695	7.5%	0	5	104 & 149,009	30 & 10,555	**491**	0.25%
2025	1.2%	Intercon	**3,000**	**9,500**	800	295	10.0%	40	105	124 & 196,248	53 & 26,306	**727**	0.42%
2025	1.2%	Isolated	**3,000**	**9,500**	600	117	10.0%	40	105	250 & 380,343	198 & 95,718	**1,351**	0.89%

Comparative Review of Recent Flexibility Assessment Studies

As part of this study, comparative review of recent flexibility assessment studies for IPS of Ukraine has also been developed. The review has included the comparison of the following studies:*

- USAID ESP - Flexibility Assessment Study for Different RES Penetration Scenarios (This Study) – 2020
- Approved Generation Adequacy Study of Ukrenergo – 2019
- Flexibility to Future-Proof the Ukraine Power System – 2018 (Wartsila)
- Balancing of Fluctuating Renewable Power Sources – 2018 (Berlin Economics)

Results of the studies have been reviewed, as well methodologies, scenarios and assumptions implemented for the assessments to the extent allowed by the disclosed information of the studies.

* Details of the comparison, including assumptions and findings are available in the full-report

Basic Economic Assessment of Flexibility Options

- 4 different flexibility options has been compared from cost perspective to the power sector of Ukraine. The assessed flexibility options include the following alternatives:
  - RES Curtailment for Downward Ramping + Pro-Active RES Curtailment for Upward Ramping
  - Gas Peaking
  - Battery Storage
  - Pump Storage
- For the economic assessment, 2025 Baseline Scenario-1 has been considered with 12.5GW RES (3000MW WPP and 9500 MW SPP) with 1.2% of annual demand increase and interconnected mode of operation.

2025, Baseline Scenario-1: 12.5GW RES, 1.2% Annual Demand Growth Interconnected Mode of Operation
Downward Ramping Deficit (RES Energy to be Curtailed, if that is the option): 196GWh, which is 1.02% of yearly RES generation (number of hours that system will be forced to RES restriction: 124 hours)
Upward Ramping Deficit (Energy Required from New Flexible Capacity): 26.3 GWh (in 53 hours)
Maximum Additional Maneuvering Capacity Required: 727 MW (capacity factor: 0.41% for upward ramping)

Considered Factor for the options

- Pre-requisites for Implementation
- Time Required for Implementation
- CAPEX Assumptions
- CAPEX
- OPEX Assumptions
- Annual OPEX
- Assumptions About Cost of Energy Restrictions
- Deemed Energy Cost of RES (Cost of RES Restrictions)

Cost Estimation and Comparison (1/4)

Criteria for Evaluation	RES Curtailment for Downward Ramping + Pro-Active RES Curtailment for Upward Ramping	Gas Peaking	Battery Storage	Pump Storage (Variable Speed)
Pre-requisites for Implementation	- RES Curtailment Management System (RES-CMS) - Short Term Load Forecast System (STLFS) - Short Term RES Forecasting System (STRESFS) - Direct Integration of WPP & SPP Controllers to Dispatch Centre (for directly sending set points to PPs)	- Identification of best sites and capacities for optimal flexibility to be provided.	- Identification of best sites and capacities for optimal flexibility to be provided.	- Identification of best sites and capacities for optimal flexibility to be provided (Limited available sites (i.e., water availability required). - Incorporation of water usage constraint is key for best design schemes.
Time Required for Implementation	- 9-12 months for implementation of analytical forecasting and management systems. - 9 to 12 months for direct integration of RES PPs to Ukrenergo Dispatch Centre	12-18 months of construction time	18 - 24 months of construction time	3-5 years of construction time
CAPEX Assumptions	- Cost of Implementation of RES-CMS, STLFS and STRESFS: 10M USD - Cost of RES Connection to Control Centre - Number of WPPs: 100 (in average 30 MW capacity) - Number of SPPs: 1250 (in average 7.5 MW capacity) - Cost of RTU panel with all SCADA engineering for each WPP: 100k USD - Cost of RTU panel with all SCADA engineering for each WPP: 20k USD	- Build Cost: 700$/kW - Installed Capacity of 727 MW	- Assumed that each unit will be 10MW/40MWh - Initial Capital Cost-AC: 70$/kW - Initial Capital Cost-DC: 228$/kWh - Installed Capacity of 727 MW/2908MWh	- Assumed that each unit will be 100MW/800MWh - Installed Capacity of 727MW/5,816MWh - Build Cost: 238$/kWh
CAPEX (Million USD)	45.0	508.9	713.9	1384.2

Cost Estimation and Comparison (2/4)

Criteria for Evaluation	RES Curtailment for Downward Ramping + Pro-Active RES Curtailment for Upward Ramping	Gas Peaking	Battery Storage	Pump Storage (Variable Speed)
OPEX Assumption	- Annual OPEX of Automation System: 10% of CAPEX - Annual OPEX of Analytical IT System: 10% of CAPEX	- Fixed O&M: 7$/kW-yr - Variable O&M: 4.7$/MWh - Heat Rate: 8000 Btu/kWh - Capacity Factor (for upward ramping): 0.41% - Capacity Factor (for downward ramping): 3.05% - Fuel Price: 2$/MBtu	- O&M: 0.8$/kWh - Warranty Expenses in % of CAPEX: 3% - Loss of Energy due to Efficiency of Storage: 10% - Average MWh Energy price: 30$/MWh - For upward ramping deficit: 26.3GWh - For downward ramping deficit: 196GWh	- Fixed O&M: 1% of OPEX annual. - Variable O&M: 4$/MWh - Loss of Energy due to Efficiency of PSHPP: 20% - Average MWh Energy price: 30$/MWh - For upward ramping deficit: 26.3GWh - For downward ramping deficit: 196GWh
Annual OPEX (Million USD)	4.5	461.2	178.5	16.1

Cost Estimation and Comparison (3/4)

Criteria for Evaluation	RES Curtailment for Downward Ramping + Pro-Active RES Curtailment for Upward Ramping	Gas Peaking	Battery Storage	Pump Storage (Variable Speed)
Assumptions About Cost of Energy Restrictions	- For downward ramping, the system will have 196GWh of deficit, that will be curtailed from RES generation. - For provision of upward ramping of 26.3 GWh (53 hours) required from RES via pro-active curtailment, we assume that despite the fact that analytical tools will be used, due to certain error margin of forecasting, more RES will be curtailed then the actual system requirement, which also have been incorporated in the cost calculation. Furthermore, additional incentive for RES power plants to support this upward ramping needs is also estimated. - Assumed unit price for curtailed RES generation: 135$/MWh - Assumed unit price for upward regulation in balancing market: 55$/MWh	Assumed as zero.	Assumed as zero.	Assumed as zero.
Deemed Energy Cost of RES (Cost of RES Restrictions) (Million USD)*	45.7	0	0	0

*Some curtailment is to avoid more expensive upward ramping shortages.

Cost Estimation and Comparison (4/4)

Criteria for Evaluation	RES Curtailment for Downward Ramping + Pro-Active RES Curtailment for Upward Ramping	Gas Peaking	Battery Storage	Pump Storage (Variable Speed)
Total Cost (5 years) (Million USD)	295.8	2815.0	1606.4	1464.5
Total Cost (20 years) (Million USD)*	1048.2	9733.2	4284.1	1705.5

*For the sake of simplification, it has been assumed same ramping deficit will be experienced for the cost calculation time horizon as it's expected in 2025 baseline scenario (As the results of cost calculation is only used for comparison of the mentioned flexibility options, an NPV study hasn't been executed).

THANK YOU!

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USAID UKRAINE CONTACT

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