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Policy advice on low-carbon policies for Ukraine

IKI INTERNATIONALE KLIMASCHUTZINITIATIVE

Supported by

Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection

Based on a decision of the German Bundestag

Ukraine's power plant park: Optimal configuration in 2032 and investment needs in the transition phase

Manuel von Mettenheim, Rouven Stubbe, David Saha

Berlin, February 2022

Implemented by

Berlin Economics

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Structure

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Policy context & Objective

Policy context:

Updated NDC

- -65% of GHG emissions by 2030 (compared to 1990 levels)
- Bulk of emissions reduction in power sector to compensate for growing industry sector

National Emission Reduction Plan (NERP)

- EU Directives require expensive retrofitting or decommissioning of TPPs

Post Coal Alliance

- COP26: coal phase-out by 2035/2040

Objective:

- Find **optimal power plant park in 2032**, consistent with (a) cost-efficient implementation of **Updated NDC** and (b) **IED/NERP process**
- Outline a feasible **transition path** & estimate **investment needs**

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Part I:
Optimal power plant park in 2032

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1. Analytical approach

Preparatory work

1. **Deriving policy constraints** for model-based optimisation:
   Efficient NDC implementation (using CO_2 shadow price trajectory) implies a complete coal phase-out for electricity generation until 2032

2. **Defining of current policies scenario** and **model-based optimisation** of target scenario

Modelling approach for each scenario

3. Modelling **optimal dispatch** to derive the minimum variable cost usage for 2032 (Optimal Dispatch Model)

4. Deterministically verifying **adequacy** (Reserve margin approach)

5. Calculating **total system costs** (Power Sector Financial Model)

6. Comparing scenarios regarding investment needs and annual system costs

Comparison of scenarios, policy implications

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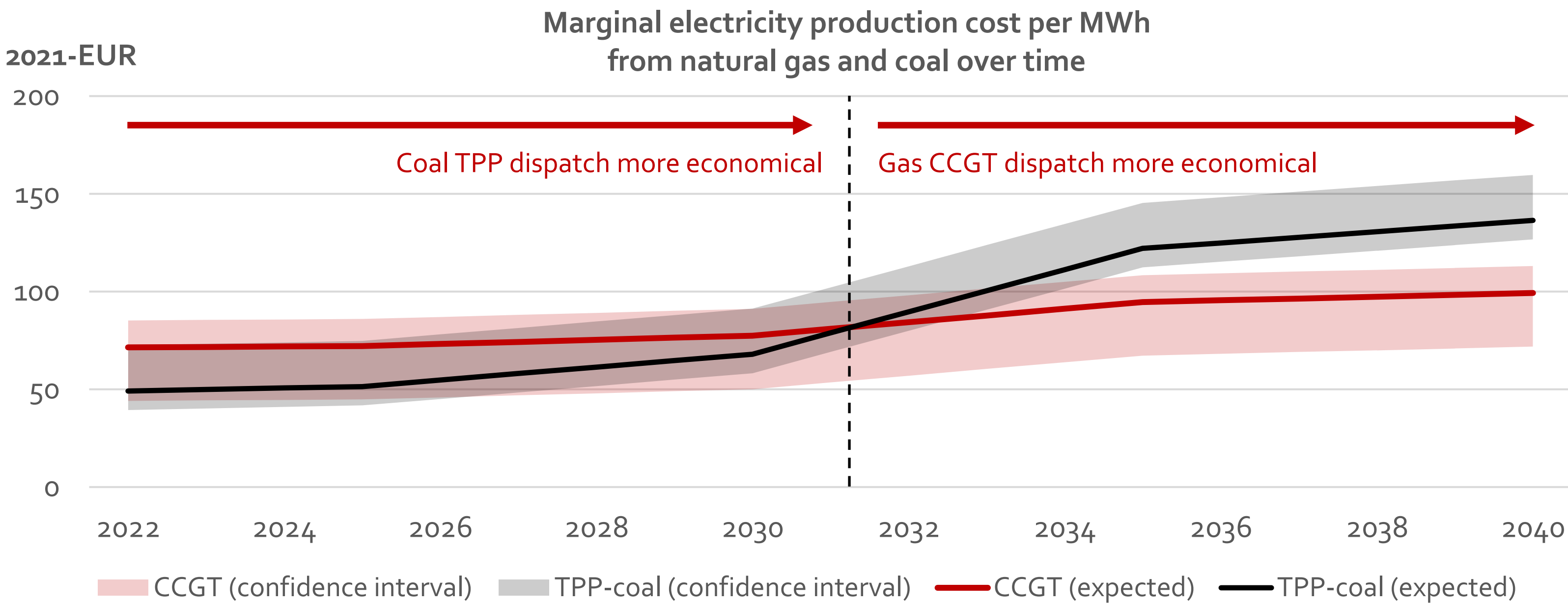
2. Implication of decarbonisation for TPP investments

- **Efficient NDC implementation** (using CO_2 shadow price trajectory) implies that renewables & gas turbine generation **should replace TPP generation by 2032** (details in Annex II & III).



Source: Own calculations based on TIMES modelling results, JRC, Heat Roadmap Europe

- Comparison of annual Capex per kW for **new CCGT** and **existing TPP** (Annex IV)

EUR 143 < **EUR 173-622**

➢ **Investment in existing TPP (filter and lifetime extension) cannot be amortised before shutdown in 2032**

➢ **This implies a complete coal phase-out for electricity generation until 2032.**

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3. Scenarios for the power plant park in 2032

	Current policies scenario	LCU Target scenario
TPP capacity	Current NERP: units are either retrofitted (lifetime extension + filter) or decommissioned and (partly) replaced	• no retrofits • no replacements with coal-fired generation • move all TPPs in Annex III (filter retrofit) to Annex IV A2 (40k hours limit)
Nuclear capacity	Khmelnytskyi NPP units 5 and 6 (2.2 GW) are newly built	
Renewable capacity (excl. hydro)	Increase follows preliminary auction volumes by MinEnergo	RES capacities are optimized
Gas turbines	–	Gas turbines are optimized

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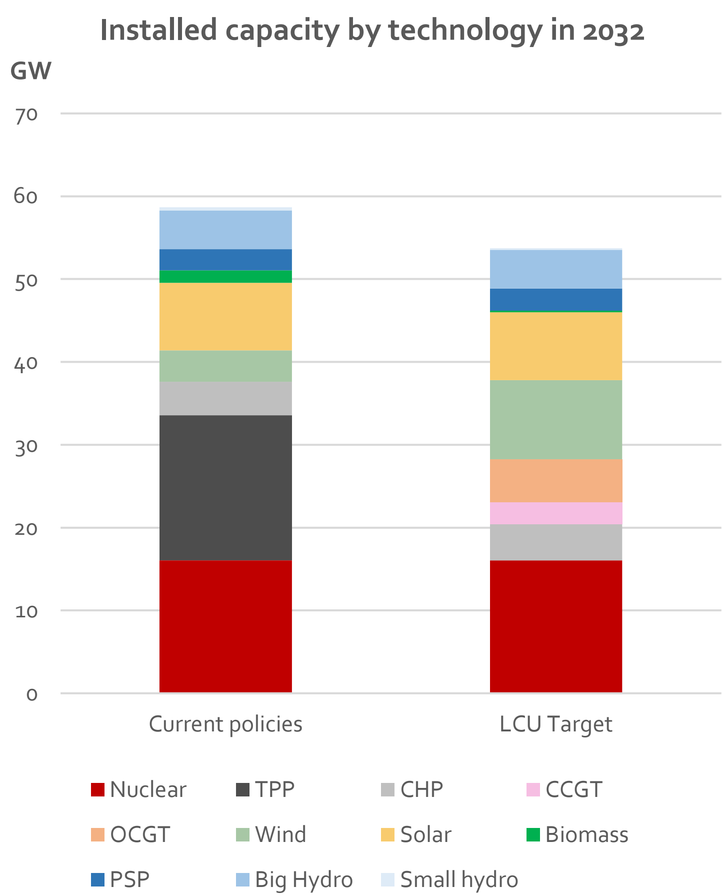
3.1 Installed capacity



Replacement needs for coal-fired TPPs by 2032

8 GW wind turbines
(+6 GW compared to Current Policies)

2 GW solar plants
(equal to Current Policies)

8 GW gas turbines

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Supply, storage & demand side flexibility options

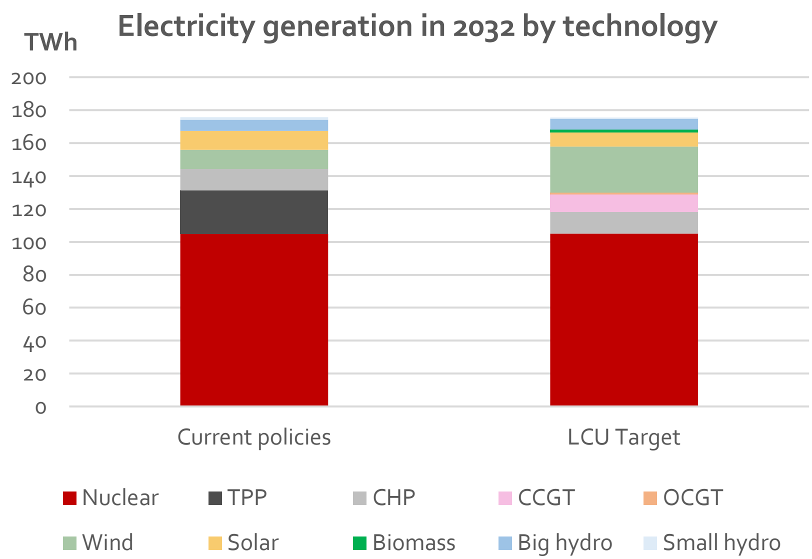
Major challenge in Ukrainian electricity system

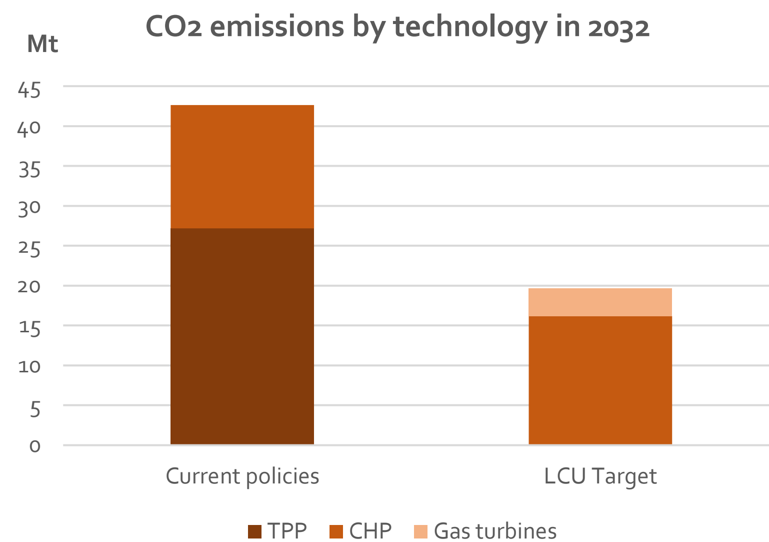
Introduce more flexibility in electricity system to combine
high share of nuclear baseload generation & growing share of variable RES

	Technology	Flexibility	Advantage	Disadvantage	Considered in model
Supply side	CCGT	mid-term	High efficiency	High O&M costs	Yes
	OCGT	short- & mid-term	Relatively low Capex	High variable cost	Yes
	ICE	short- & mid-term	Relatively low Capex	High variable cost	No, but ICE and OCGT are quite similar
	Biogas + storage	short- & mid-term	Already mature low-carbon technology	High Capex	Not as flexible option
Storage	Battery	short-term	High flexibility	High variation in cost projections	Yes
	PSP	short-term (mainly)	Mature technology, often cost-effective	Constrained by location of suitable sites	Yes, but fixed capacity
	Power-to-gas	long-term	Option for seasonal storage	Not mature technology, very high variable costs	No
Demand side	Demand side management	short- & mid-term	Low-cost option, fuel saving	Retail consumers: Tariffs & appliances not in place*	No (uncertainty in size of demand flexibility)

*Need for smart meters & flexible tariffs to induce retail consumer demand side flexibility (industrial demand side management already possible)

3.2 Generation shares & Emissions





Gas turbines

- Provide needed balancing capacity and backup (7% of total generation)
- Gas consumption increases to **2.1 bcm annually** (≈ 7% of current total gas consumption)

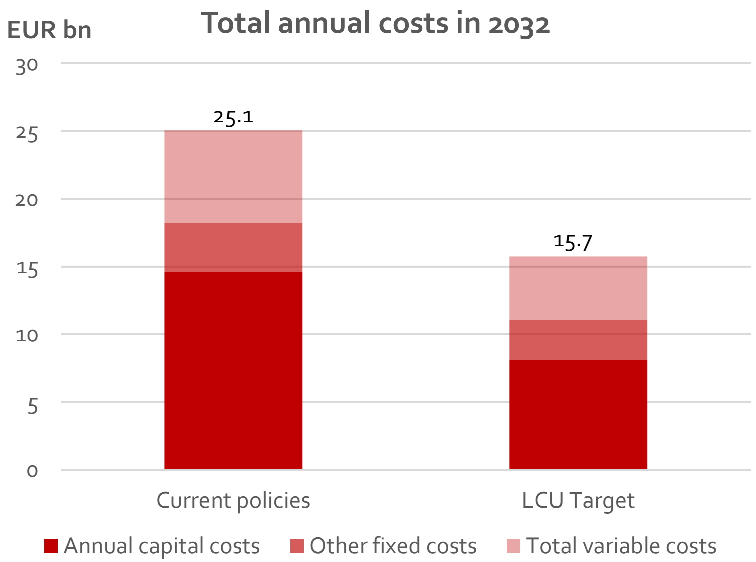
Wind and solar

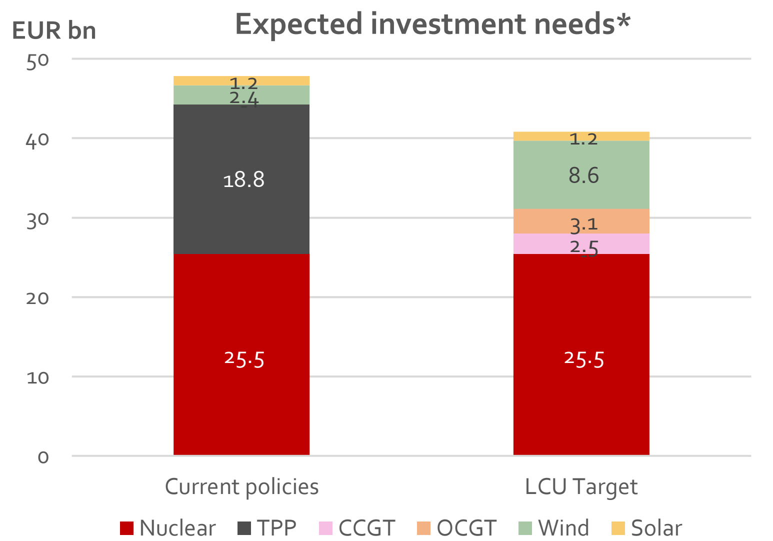
- Significant increase in Target scenario covering **21%** of total generation

Emissions

- **Sharp decline** in emissions to around 20 Mt in Target scenario
- Gas-fired electricity generation from **OCGT and CCGT** accounts for 18% of total emissions

3.3 Total system costs



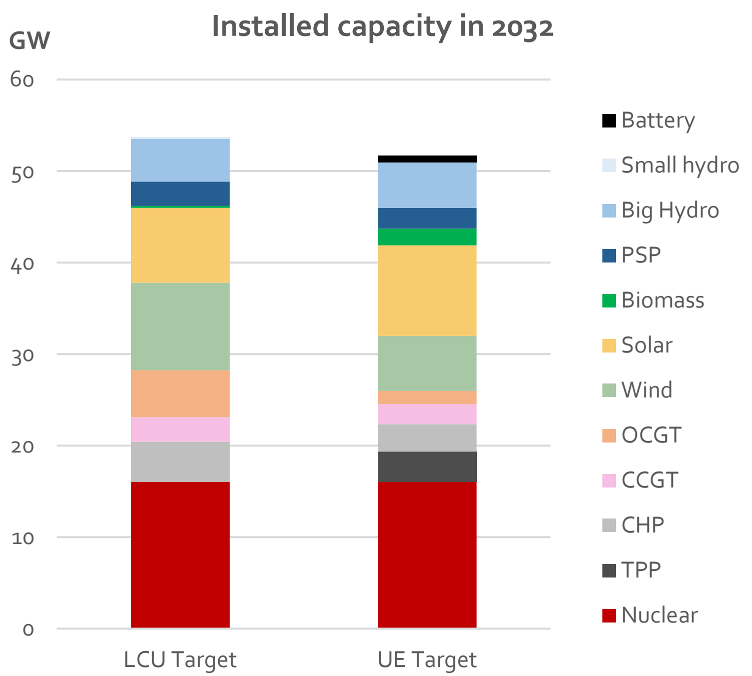


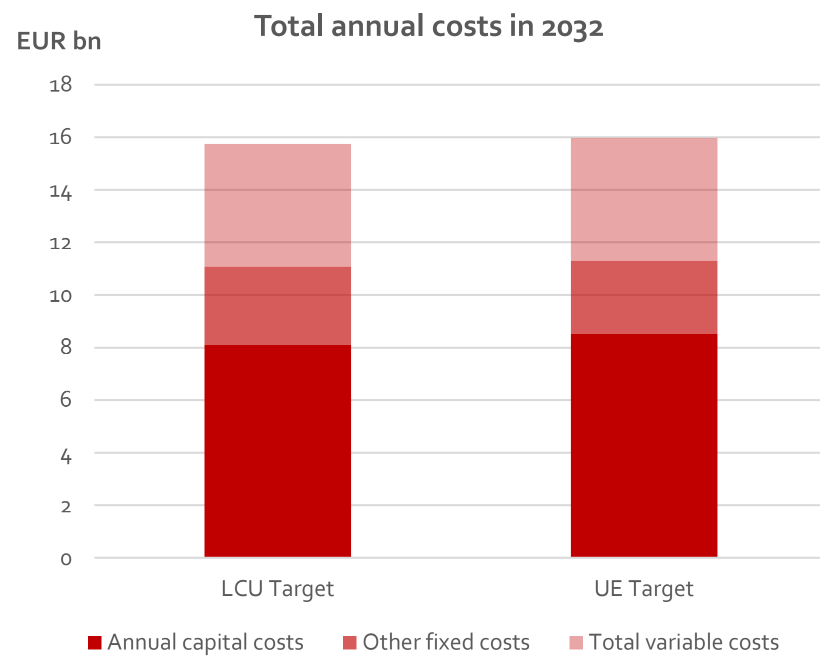
**for selected technologies since investment in Hydro, CHP, and biogas do not change across scenarios*
Note: We consider greenfield, lifetime extension and filter investment.

- Annual capital costs of Current Policies scenario exceed Target scenario due to **retrofit and replacement investment for TPPs**
- Variable costs lower in Target scenario due to **high share of RES** generation

- High investment needs in Current Policies scenario due to **retrofit and replacement investment for TPPs**
- Target scenario still requires high investment for **new nuclear units** and in extending the lifetime of about half of the current units

3.4 Comparison with Ukrenergo Target scenario





- The composition of generation technologies are quite similar in both scenarios
- In Ukrenergo Target scenario, **3.3 GW of TPPs** remain in system until 2032
  - Due to differing assumptions, some TPPs might still be economical in 2032
- Capacity of **solar and wind** is higher in LCU Target scenario
  - 18 GW vs. 16 GW (Ukrenergo)

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Part II:
Investment needs in transition phase

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4. IED/NERP process has major implications for transition phase

	Current policies	LCU Target scenario
NERP	**12.6 GW**	–
TPPs that will receive SO_2, NO_x and/or dust filter and are not foreseen for closure		
20k hours (2023)	**0.9 GW**	**0.9 GW**
Opt-out: TPPs that are allowed to operate 20,000 hours between 2018 and end-2023 and are then decommissioned (current policies: replacement with new coal-fired generation)		
40k hours (2033)	**3.3 GW**	**15.9 GW**
Opt-out: TPPs that are allowed to operate 40,000 hours between 2018 and end-2033 and are then decommissioned (current policies: replacement with new coal-fired generation)		
40k hours (2033) (gas-fired)	**5.4 GW**	**5.4 GW**
Opt-out: TPPs that are allowed to operate 40,000 hours between 2018 and end-2033 and are then decommissioned		
New wind and solar	**3 GW**	**10 GW**
Cumulative construction of new wind & solar PV foreseen for 2022-2030 (commissioned in 2032)		
New gas turbines	–	**8 GW**
Cumulative construction of OCGT & CCGT foreseen for 2022-2030 (commissioned in 2032)		

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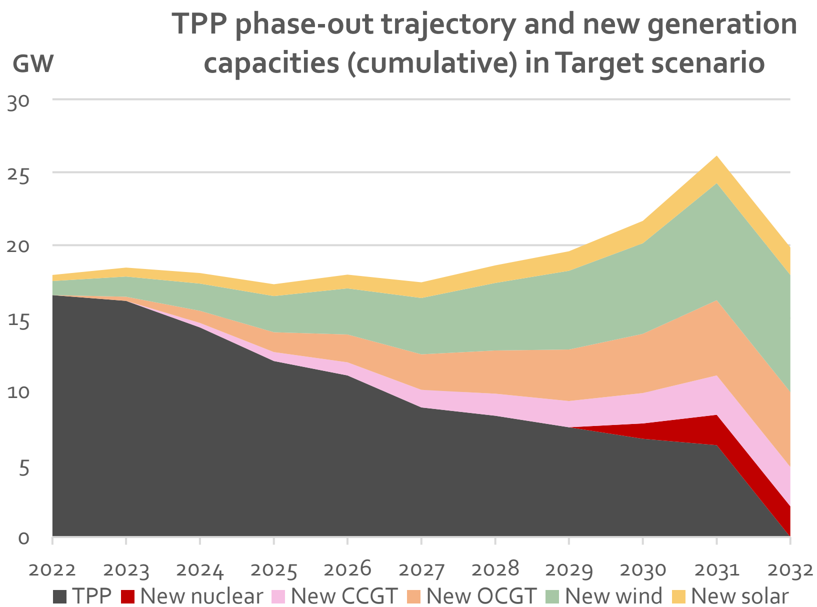
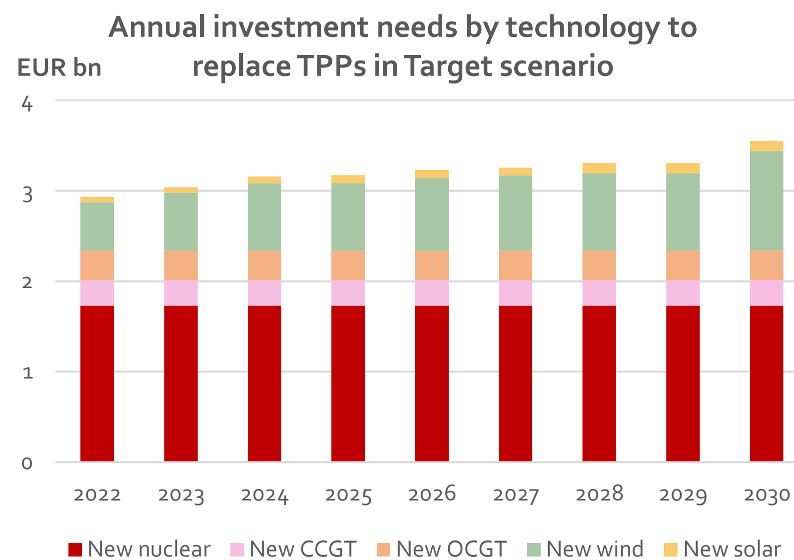
5. Outlining feasible transition path





Note: we assume investment two years before plant is commissioned except for nuclear investment which is evenly distributed from today

- Timing of new investment is determined by exhaustion of TPP **operating hour limits**
- On average 1.1 GW of TPPs will have to stop operation every year until 2031
  - **2031: 6 GW of TPPs will close**
- ➢ Construction of new RES & gas turbines must be tackled quickly (construction time: **~2 years**)

- **EUR 1.2 - 1.8 bn** annual investment into new RES & gas turbine construction in this decade
- Additionally, **EUR 1.7 bn** p.a. needed for construction of Khmelnytskyi units 5 and 6
- **Investments should start quickly** to ensure security of supply in the transition phase
- **RES auctions could be scaled up over time** (with a steep path)

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Summary & Policy Implications

Analysis	**NDC**		**TPP phase-out until ~2032**
	IED/NERP		Current NERP unviable, retrofits uneconomical
			Operating hour limits: **TPP capacity ↓ from 2024**
Policy Implications	**Revise NERP**		no retrofits, no replacements, move all TPPs to Annex IV A2 (40k hours limit)
	Investment needs		**around EUR 3.2 bn per year** (EUR 29 bn until 2030)
		RES	8 GW wind 2 GW solar
		Gas turbines	8 GW CCGT & OCGT (should be H2-ready)
		NPP	**Strategic decision:** the construction of two new Westinghouse nuclear reactors (2.2 GW) already decided
	Further assessment needed	CHP	Beyond the scope of this work, see Annex VI

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Implemented by:

Berlin Economics

Head of Energy and Climate
David Saha
saha@berlin-economics.com

Project Manager
Denis Kletzel
kletzel@berlin-economics.com

www.lowcarbonukraine.com

Tel.: 030 2064 34 64 – 0

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Annex overview & analytical approach (detailed)

Defining a least-cost, adequate power plant park compatible with Ukraine's decarbonisation targets

- Minimising total system costs, i.e.
  - Variable cost (fuel cost, CO_2 price, variable O&M)
  - Fixed cost (annuity for capital expenditure, fixed O&M)
  - Cost assumptions mainly based on JRC, IEA, HeatRoadmap Europe and own calculations (Annex I)
  - CO_2 shadow price and amortisation periods for coal power plant retrofits based on TIMES modelling (Annex II) and own calculations (Annex III, IV)
- Least-cost NDC implementation requires an increasing cross-sectoral CO_2 price (see Annex II)
  - Determined with technoeconomic energy modelling (TIMES)
  - Affects assumptions for power-sector modelling (Optimal Dispatch Model & Power Sector Financial Model)

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Annex I: Table of relevant assumptions

Type of cost	Technology/fuel	Unit	Value	Source
Fuel costs	Coal	EUR/MWh	15	Heat Roadmap Europe (2017)
	Natural gas	EUR/MWh	42	Heat Roadmap Europe (2017)
	Biomass	EUR/MWh	26	Heat Roadmap Europe (2017)
	Nuclear	EUR/MWh	2	Ukrenergo
Capex for greenfield	All technologies, incl.			JRC (2019)
	OCGT	EUR/kW	610	JRC (2019)
	CCGT	EUR/kW	933	JRC (2019)
	TPP	EUR/kW	1,772	JRC (2019)
	Wind	EUR/kW	1,070	JRC (2019)
	Solar	EUR/kW	614	JRC (2019)
	Biogas (FBC)	EUR/kW	2,950	JRC (2019)
	and others*	EUR/kW	-	JRC (2019)
Capex lifetime extension	All technologies	EUR/kW	$Capex * 25\%$	JRC (2019), DIW (2013)
Fix O&M	All technologies *	EUR/kW	-	JRC (2019)
Variable O&M	All technologies	EUR/kWh	-	JRC (2019)
Capex filter	SO2	EUR/kW	97	Badyda et al. (2016)
	Nox	EUR/kW	60	Badyda et al. (2016)
	Dust	EUR/kW	60	Badyda et al. (2016)
	Other	EUR/kW	11	Badyda et al. (2016)
Fix O&M filter	SO2	EUR/kW	4.1	Badyda et al. (2016)
	Nox	EUR/kW	0.3	Badyda et al. (2016)
	Dust	EUR/kW	0.4	Badyda et al. (2016)
	Other	EUR/kW	0.4	Badyda et al. (2016)

* Capex of battery is obtained from IEA (2020); fix O&M of battery is obtained from Cole & Frazier (2019)

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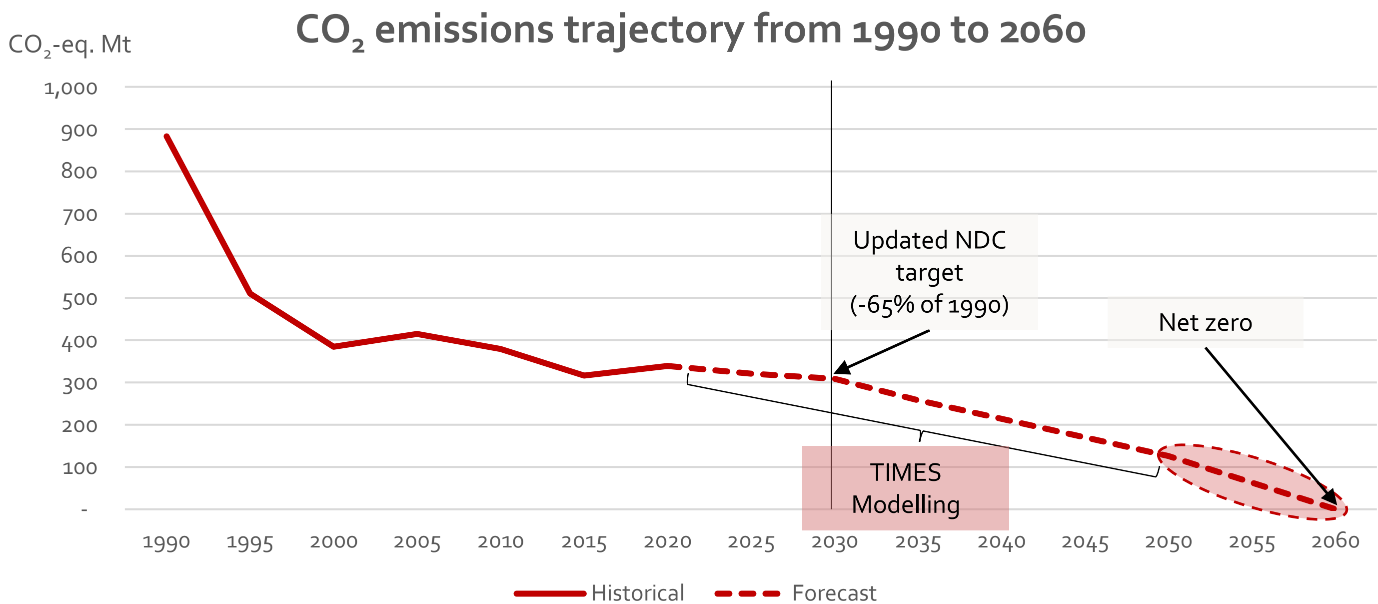
Annex II (a): Modelling Ukraine's decarbonisation goals



Source: own illustration based on Ministry of Energy and Environmental Protection of Ukraine (2020), Updated NDC, National Economic Strategy until 2030, TIMES modelling results; Note: non-CO_2 emissions are included in this graph

CO_2 emissions reduction development

- 1990-2000: sharp decline in CO_2 emissions due to economic downturn
- Since 2015: upward trend of emissions
- 2020-2030: slight reduction of CO_2 emissions to reach updated NDC target (-65% of 1990)
- 2030-2040: Emissions reduction accelerates
- 2040-2060: Further acceleration – average annual reduction to reach climate neutrality in 2060

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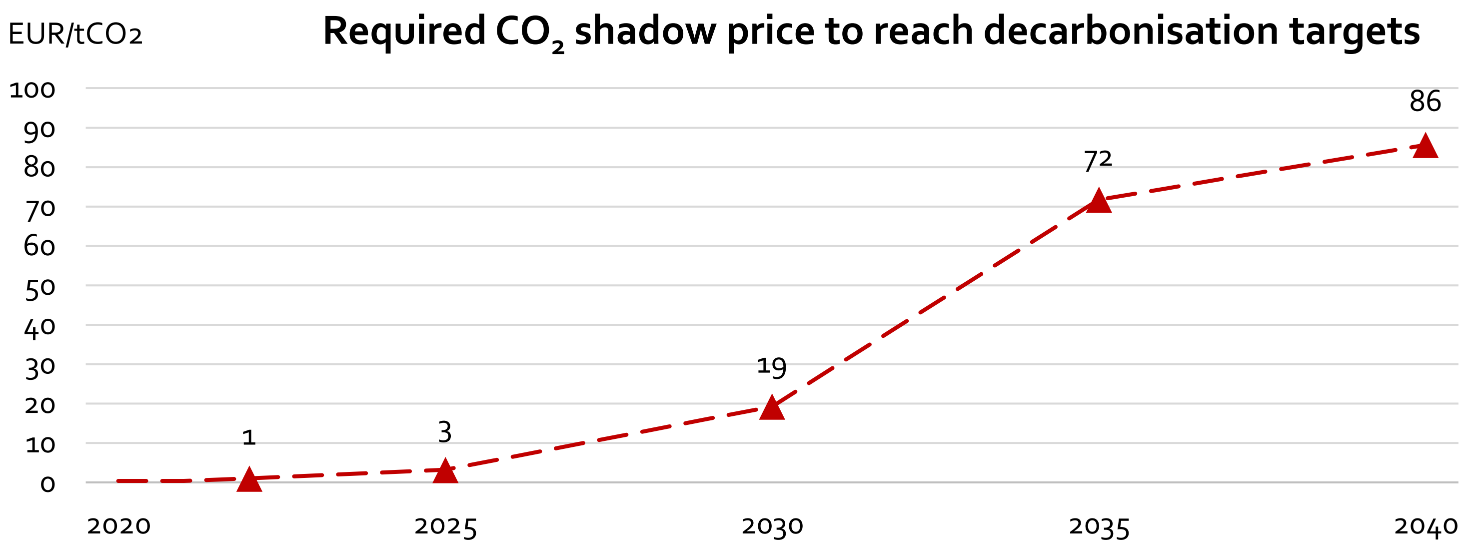
Annex II (b): CO_2 shadow price trajectory for a least-cost NDC implementation



Source: TIMES modelling results, European Commission, Ember, Ariadne Project, Refinitiv, S&P; *constant 2021 prices

- 2030 required CO_2 shadow price similar to expected CO_2 price in China by 2030 and significantly lower than in the EU (55-190 EUR/tCO_2)
- Relatively steep increase required between 2030 and 2035

➢ **For smoother CO_2 shadow price path until 2035, path until 2030 could be made more ambitious, e.g. up to 35 EUR/tCO_2 by 2030**

Annex III (a): Climate goals & required CO_2 shadow price path shortens amortisation periods for required coal TPP retrofits

- Required retrofits
  - **Lifetime extension**: All existing TPPs were built before 1989 (except two TPP units currently under construction) so that investments in lifetime extension are necessary
  - **NERP**: Large-scale required investments in filters for SO_2, NO_x and dust
- Coal power plants face a **limited economically useful lifetime**
  - Ukraine's climate goals and commitments (2030 Updated NDC, 2060 climate neutrality) requires an increasing CO_2 shadow price path for a least-cost implementation of these targets (see previous Annex II)
  - Beyond a carbon price of ca. **33 EUR/tCO_2** (see calculations on next pages), coal TPPs fall behind combined-cycle gas turbines (CCGT) in the dispatch merit order and are thus less economical than gas power plants
  - From a dynamic least-cost perspective*, at the year this CO_2 shadow price is reached, coal TPPs should be replaced with modern gas power plants (and RES which has near-zero marginal costs and rapidly falling capital investment costs)

* Since the carbon price would have to increase further in the following years, making coal TPPs even less economical from that point onwards.

Annex III (b): Determining the merit order switch between coal & gas

At what CO_2 shadow price (and thus, in what year) will coal units (TPP) and natural gas units (CCGT*) switch their positions in the dispatch merit order, as marginal electricity production costs of coal-TPP surpass CCGT?

- ➢ We calculate marginal electricity production costs for both technologies under different fuel price scenarios and CO_2 shadow prices (see graph on following page)

* as the comparable technology for a load-following generation technology

<table>
<tr><th colspan="2">Technology and fuel price scenario</th><th>Fuel price (2021-EUR/MWh**)</th><th>Efficiency</th><th>Variable O&M (2021-EUR/MWh**)</th><th>CO_2 content (tCO_2/MWh**)</th></tr>
<tr><td rowspan="3">TPP (coal)</td><td>cheap coal</td><td>11.8</td><td rowspan="3">0.33</td><td rowspan="3">2.6</td><td rowspan="3">0.34</td></tr>
<tr><td>projected coal</td><td>15</td></tr>
<tr><td>expensive coal</td><td>22.7</td></tr>
<tr><td rowspan="3">CCGT (natural gas)</td><td>cheap gas</td><td>25.3</td><td rowspan="3">0.61</td><td rowspan="3">2.2</td><td rowspan="3">0.2</td></tr>
<tr><td>projected gas</td><td>42</td></tr>
<tr><td>expensive gas</td><td>50.4</td></tr>
</table>

**CO_2 content and fuel price is per MWh-thermal, variable O&M is per MWh electric
Source: JRC, Heat Roadmap Europe

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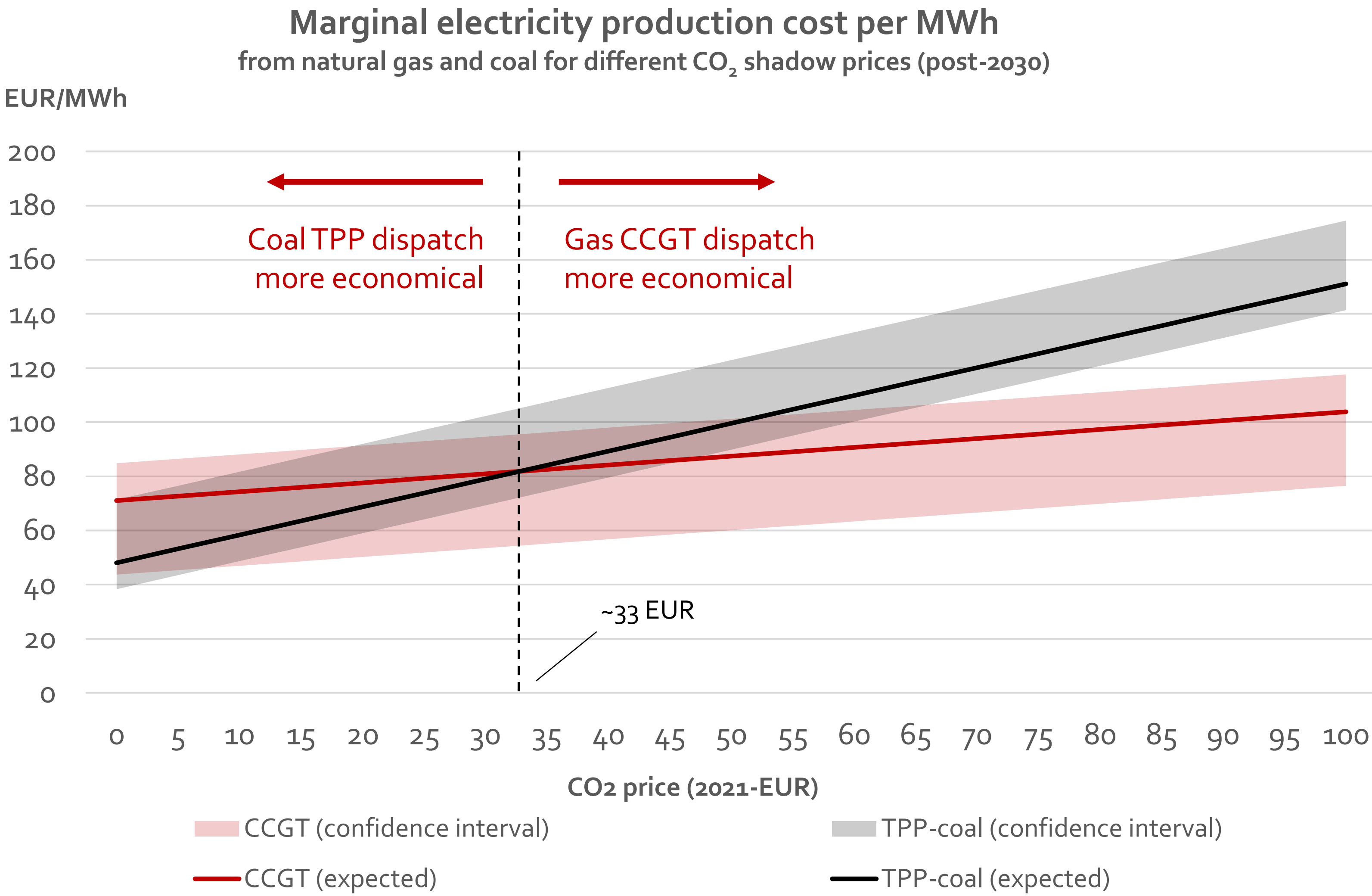
Annex III (b): Determining the merit order switch between coal & gas



Source : Own calculations based on TIMES modelling results, JRC, Heat Roadmap Europe

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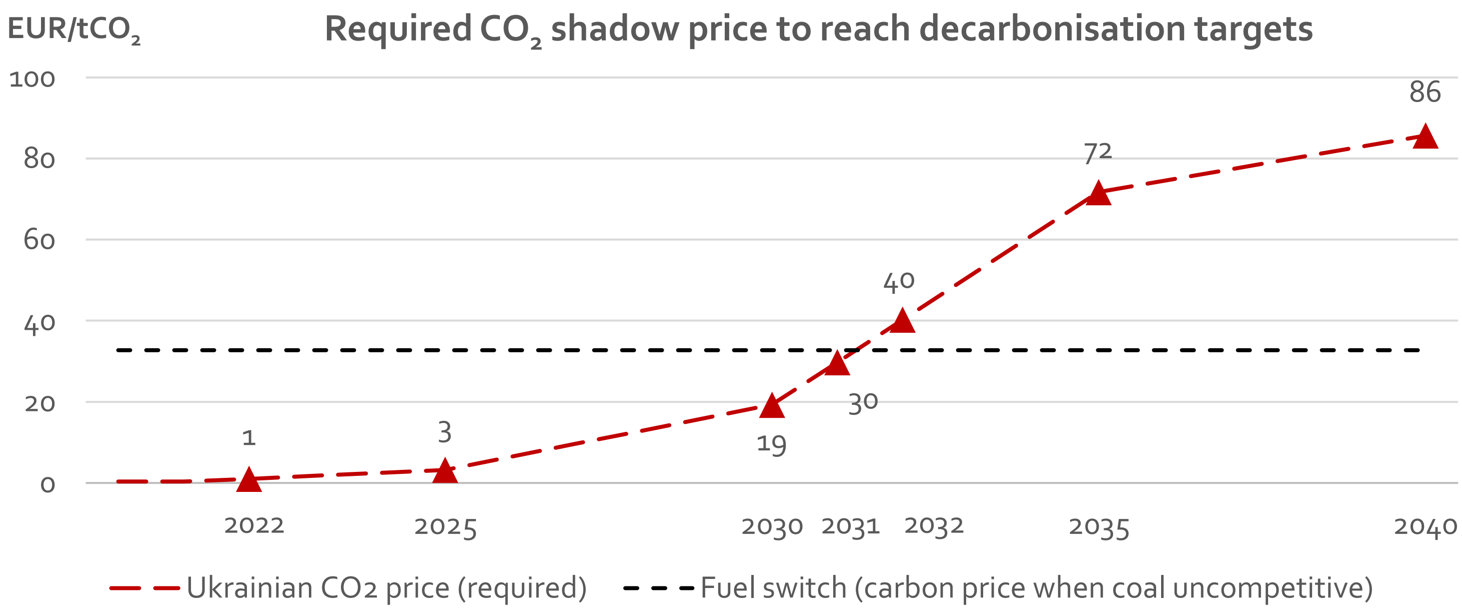
Annex III (b): Determining the merit order switch between coal & gas



Source: TIMES modelling results, European Commission, Ember, Ariadne Project, Refinitiv, S&P; *constant 2021 prices

- Coal TPPs are expected to be uneconomical after 2031/2032

➢ Annuity for retrofits (lifetime extension & filters) for coal TPPs needs to be calculated for a **shortened amortisation period** (from the year of retrofit until incl. 2031)

Annex IV (a): Overview of Ukrainian TPPs

Status of TPP units		Capacity in GW	Units	Average age in years	Description
NERP – Annex III		12.6	47	52	TPPs receive SO_2, NOx and/or dust filter
Opt-out (Annex IV A1, A2 and B)	20,000 hours until 2023	0.9	5	55	Between 2018 and end-2023, TPPs are allowed to operate 20,000 hours and are then decommissioned and replaced with coal-fired generation
	40,000 hours until 2033	3.3	13	55	Between 2018 and end-2033, TPPs are allowed to operate 40,000 hours and are then decommissioned and replaced with coal-fired generation
	40,000 hours until 2033 (gas-fired TPPs)*	5.4	8	46	Between 2018 and end-2033, TPPs are allowed to operate 40,000 hours and are then decommissioned
New TPP units**		0.7	2	0	TPPs are currently being built
Total		**22.9**	**75**		

* Gas-fired TPP were rarely in operation in previous years
** Slovyansk TPP 6a and b completed by 2023/2024

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Annex IV (b): Annuity calculation for fossil generation technologies

Power plant	Unit	Status	Capacity in MW	Capex in EUR m	Capex annuity In EUR m	Annuity per kW in EUR
CCGT	-	Greenfield	100	93.3	14.2	142
OCGT	-	Greenfield	100	61.0	9.4	94
Dobrotvorska TPP	5	Unknwon	100			
	6	Unknown	100			
	7	NERP	150	100.5	38.1	254
	8	NERP	160	107.2	39.1	248
Ladyzhynska TPP	1	NERP	300	201.1	85.0	283
	2	NERP	300	201.1	81.3	271
	3	NERP	300	201.1	100.1	334
	4	NERP	300	201.1	76.2	254
	5	NERP	300	201.1	76.2	254
	6	NERP	300	201.1	76.2	254
Trypilska TPP	1	NERP	300	201.1	88.1	294
	2	NERP	325	217.8	102.9	317
	3	NERP	300	201.1	95.0	317

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Annex IV (b): Annuity calculation for fossil generation technologies

Power plant	Unit	Status	Capacity in MW	Capex in EUR m	Capex annuity In EUR m	Annuity per kW in EUR
Trypilska TPP	4	NERP	300	201	76	254
	5	40k hours 2033 (gas)	300	-	-	-
	6	40k hours 2033 (gas)	300	-	-	-
Kurakhivska	3	NERP	200	134	55	274
	4	NERP	210	141	53	254
	5	40k hours 2033	222	393	172	776
	6	40k hours 2033	225	399	175	776
	7	40k hours 2033	225	399	175	776
	8	NERP	225	116	48	213
	9	NERP	225	151	56	248
Luganska TPP	9	NERP	200	134	52	264
	10	NERP	210	141	62	294
	11	NERP	200	115	46	228
	12	Offline	175	-	-	-
	13	NERP	210	108	45	213
	14	NERP	200	134	51	254

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Annex IV (b): Annuity calculation for fossil generation technologies

Power plant	Unit	Status	Capacity in MW	Capex in EUR m	Capex annuity In EUR m	Annuity per kW in EUR
Luganska TPP	15	NERP	200	115	46	228
	TEG 4	Offline	100	-	-	-
Slovyanska TPP	3	Unknown	80			
	4	Offline	80	-	-	-
	7	NERP	720	483	183	254
	6a	Greenfield	330	585	130	395
	6b	Greenfield	330	585	141	426
Vuhlehirska TPP	1	NERP	300	201	95	317
	2	NERP	300	201	95	317
	3	NERP	300	201	84	279
	4	NERP	300	201	78	258
	5	40k hours 2033 (gas)	800	-	-	-
	6	40k hours 2033 (gas)	800	-	-	-
	7	40k hours 2033 (gas)	800	-	-	-

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Annex IV (b) Annuity calculation for fossil generation technologies

Power plant	Unit	Status	Capacity in MW	Capex in EUR m	Capex annuity In EUR m	Annuity per kW in EUR
Zmiyivska TPP	1	NERP	175	117	55	317
	2	NERP	175	117	56	320
	3	40k hours 2033	180	319	140	776
	4	40k hours 2033	180	319	140	776
	5	40k hours 2033	190	337	147	776
	6	40k hours 2033	185	328	144	776
	7	NERP	290	194	82	283
	8	NERP	325	218	108	334
	9	NERP	280	188	91	325
	10	NERP	290	194	96	330
Kryvorizka TPP	1	NERP	315	211	83	263
	2	40k hours 2033	300	532	233	776
	3	NERP	300	201	92	306
	4	NERP	300	201	76	254
	5	40k hours 2033	282	500	219	776
	6	Offline	282	-	-	-

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Annex IV (b): Annuity calculation for fossil generation technologies

Power plant	Unit	Status	Capacity in MW	Capex in EUR m	Capex annuity In EUR m	Annuity per kW in EUR
Kryvorizka TPP	7	Offline	282	-	-	-
	8	40k hours 2033	282	500	219	776
	9	Offline	282	-	-	-
	10	NERP	300	201	79	262
Prydniprovksa TPP	7	40k hours 2033	150	266	116	776
	8	40k hours 2033	150	266	116	776
	9	40k hours 2033	150	266	116	776
	10	40k hours 2033	150	266	116	776
	11	NERP	310	208	81	262
	12	Offline	285	-	-	-
	13	Offline	285	-	-	-
	14	Offline	285	-	-	-
Zaporizka TPP	1	NERP	325	198	79	244
	2	NERP	300	201	76	254
	3	NERP	325	218	85	261
	4	NERP	300	201	76	254

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Annex IV (b): Annuity calculation for fossil generation technologies

Power plant	Unit	Status	Capacity in MW	Capex in EUR m	Capex annuity In EUR m	Annuity per kW in EUR
Zaporizka TPP	5	40k hours 2033 (gas)	800	-	-	-
	6	40k hours 2033 (gas)	800	-	-	-
	7	40k hours 2033 (gas)	800	-	-	-
Burshtynska TPP	1	20k hours 2023	195	345	151	776
	2	20k hours 2023	185	328	143	776
	3	20k hours 2023	185	328	143	776
	4	20k hours 2023	195	346	151	776
	5	40k hours 2033	215	381	166	776
	6	20k hours 2023	195	346	151	776
	7	40k hours 2033	206	365	159	776
	8	NERP	195	131	51	262
	9	NERP	195	131	49	254
	10	NERP	210	141	52	249
	11	NERP	195	131	53	274
	12	NERP	195	131	60	254

Annex V: Installed capacity (table)

<table>
<tr><th>in MW</th><th>2021</th><th>Current policies</th><th>LCU Target (nuclear)</th><th>UE Baseline</th><th>UE Target</th><th>SAEE RES strategy until 2030</th></tr>
<tr><td>Nuclear</td><td>13,835</td><td>16,055</td><td>16,055</td><td>16,055</td><td>16,055</td><td></td></tr>
<tr><td>TPP</td><td>21,842</td><td>7,500</td><td>-</td><td>3,130</td><td>3,280</td><td></td></tr>
<tr><td>OCGT</td><td>-</td><td>-</td><td>5,141</td><td>150</td><td>1,450</td><td>1350</td></tr>
<tr><td>CCGT</td><td>-</td><td>-</td><td>2,701</td><td>-</td><td>2,200</td><td></td></tr>
<tr><td>Biofuel</td><td>200</td><td>1,500</td><td>212</td><td>820</td><td>1,817</td><td>1,500</td></tr>
<tr><td>Wind</td><td>1,529</td><td>3,778</td><td>9,554</td><td>4,900</td><td>6,000</td><td>4,700 (onshore), 300 (offshore)</td></tr>
<tr><td>Solar</td><td>6,283</td><td>8,173</td><td>8,173</td><td>6,300</td><td>9,894</td><td>7,000</td></tr>
<tr><td>Big Hydro (dams)</td><td>4,663</td><td>4,663</td><td>4,663</td><td rowspan="2">4,952</td><td rowspan="2">4,952</td><td rowspan="2"></td></tr>
<tr><td>Small hydro</td><td>364</td><td>366</td><td>182</td></tr>
<tr><td>CHP</td><td>4,059</td><td>4,059</td><td>4,367</td><td>3,000</td><td>3,000</td><td></td></tr>
<tr><td>PSP</td><td>1,488</td><td>2,562</td><td>2,660</td><td>2,287</td><td>2,287</td><td></td></tr>
<tr><td>Battery</td><td>-</td><td>-</td><td>-</td><td>214</td><td>740</td><td>640</td></tr>
</table>

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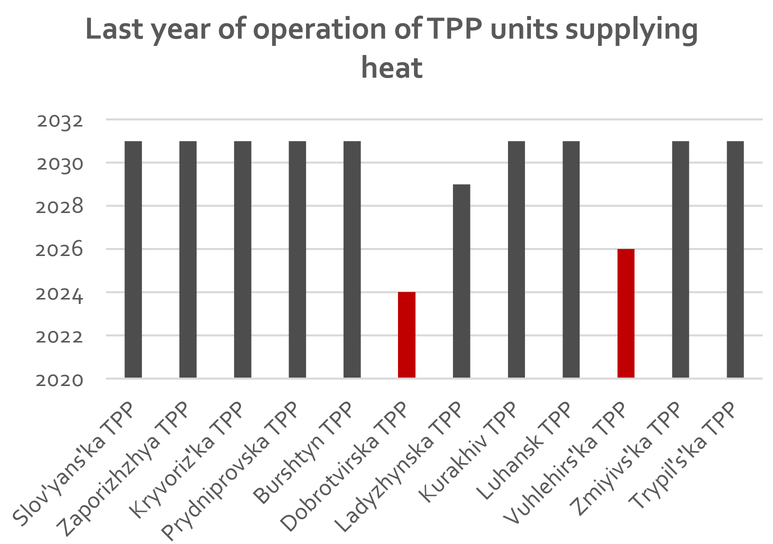
Annex VI: Considerations for heat sector

Decarbonising the electricity sector directly affects the heat sector

- Around 4.4 GW of installed capacity provides heat
  - 4.1 GW CHP capacity – no change in our calculations (exogenously included)
  - 2.8 GW TPP capacity (supplying waste heat to satellite cities) – are phased out by 2032 at the latest
- As TPPs supplying heat to satellite cities are phased out starting in 2024 (see graph below) they should be **urgently replaced** with new modern heat plants, e.g. new CHP
  - Since TPPs are oversized for heat supply, 0.3 GW new CHPs are enough to replace heat provision for satellite cities
  - We assume 0.3 GW new gas CHPs, but could potentially build biomass CHPs instead
  - We also assume retrofits of the existing old CHP fleet, however, more analysis of CHP retrofits vs. replacement is needed

➢ **Decarbonisation of the heat sector goes beyond the scope of this work, should be analysed in a separate study**
  - **Biomass and biogas CHP plants**
  - **Heat pumps (electrification)**
  - **Energy efficiency**



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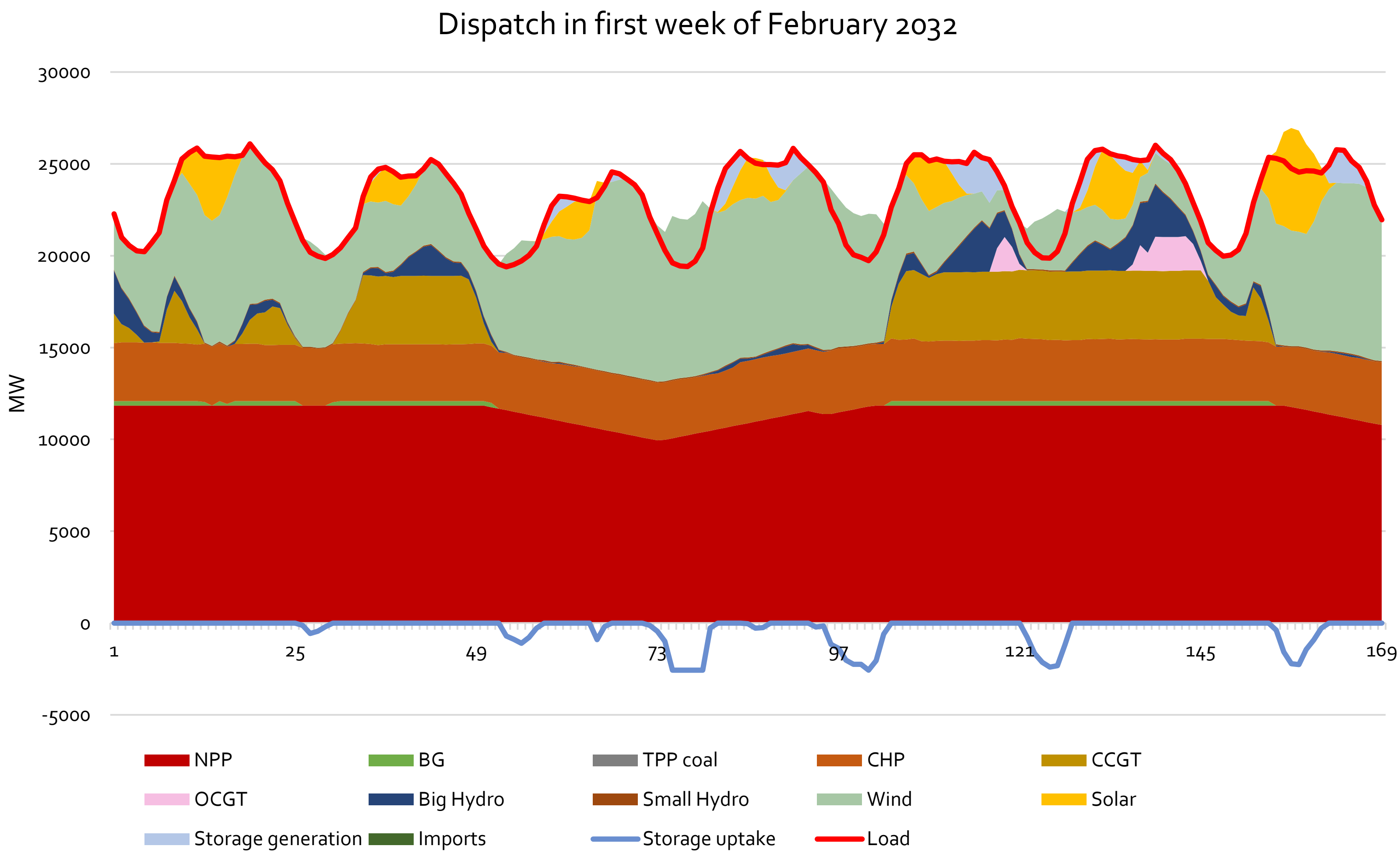
Annex VII (a): Dispatch – LCU Target Scenario (representative winter week)



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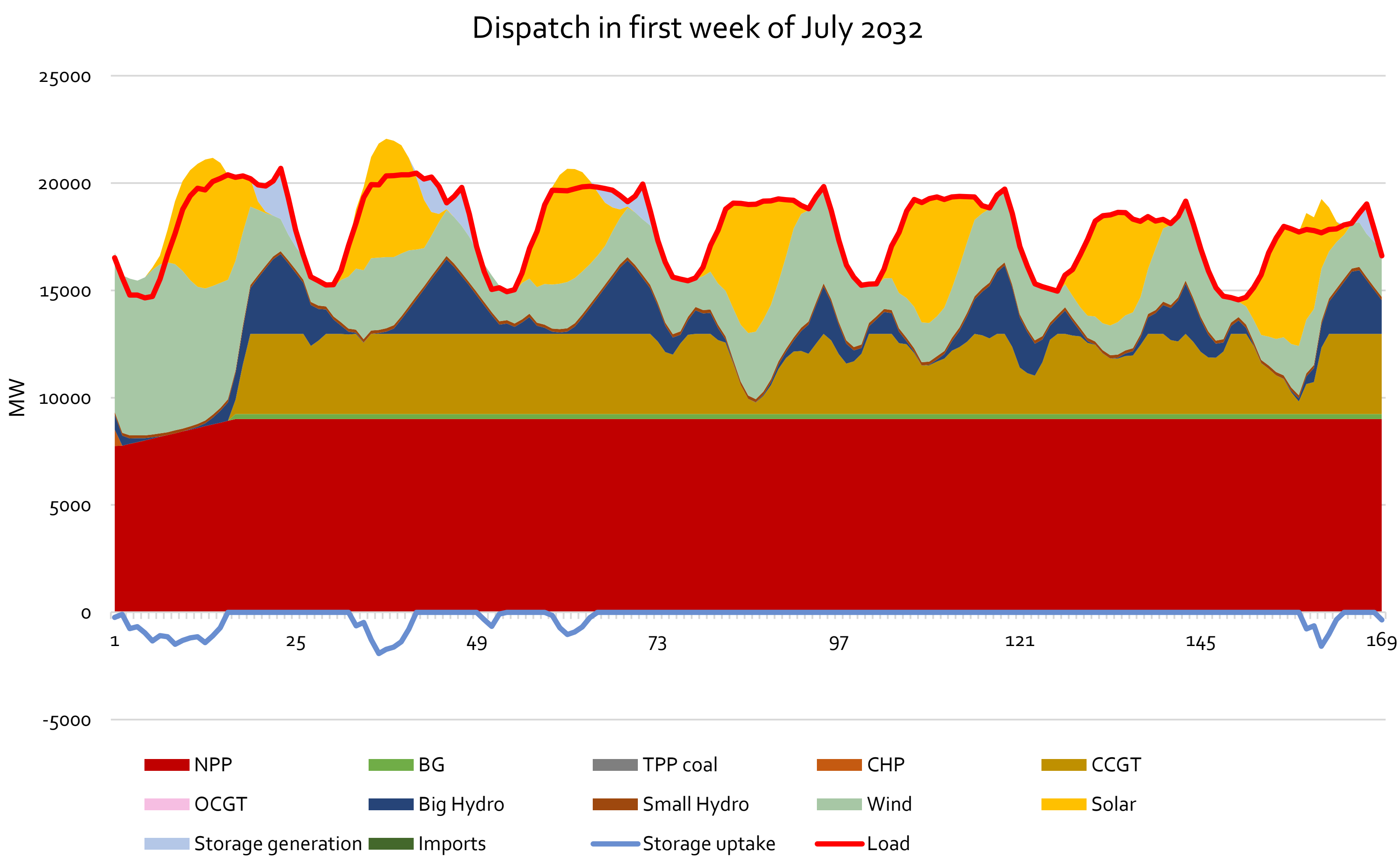
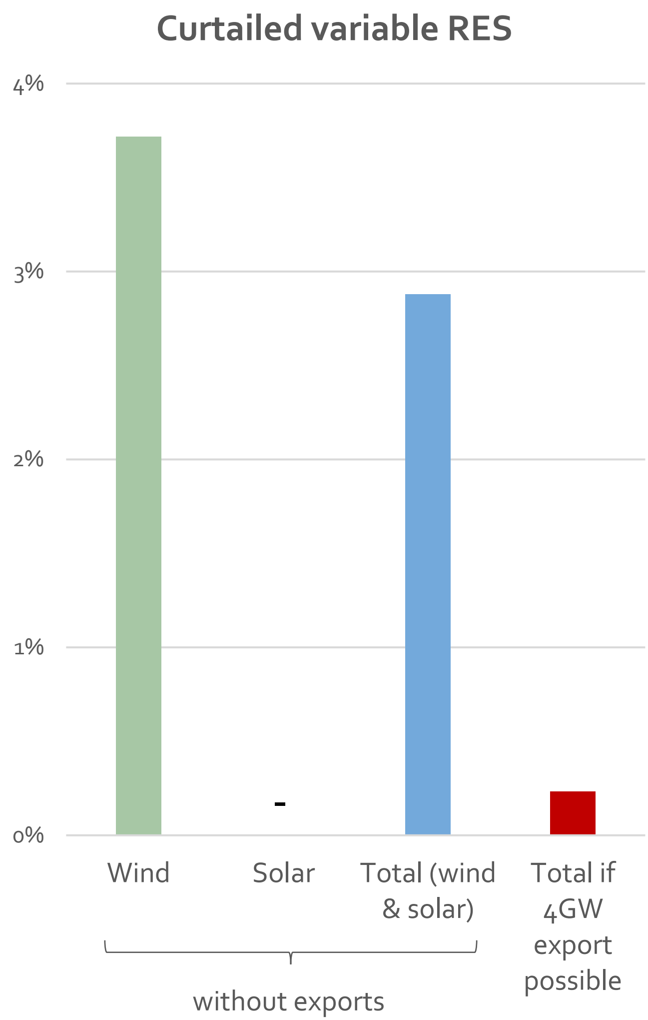
Annex VII (b): Dispatch – LCU Target Scenario (representative summer week)



Annex VII (c): Curtailment – LCU Target Scenario



	TWh
RES exported	1.34
RES curtailed	0.12

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Annex VIII: TPP Phase-out trajectory in Ukrenergo Target scenario