Low Carbon Ukraine
Policy advice on low-carbon policies for Ukraine

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RES quotas for 2020 – 2024

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About Low Carbon Ukraine

Low Carbon Ukraine is a project that continuously supports the Ukrainian government with demand-driven analyses and policy proposals to promote the transition towards a low-carbon economy.

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Executive summary

We analyse the impact of different sets of RES quotas on the Ukrainian electricity system. In our best-case scenario Ukraine would construct 3 GW of wind and solar based on existing contracts (pre-PPAs) and set RES auction quotas of 1.6 GW until 2025. The corresponding annual auctioning quotas for wind, solar, bioenergy and small hydro can be found in the table below. This pathway has four advantages over other analysed pathways:

1. It provides investment security by recognising the legal status of existing contracts and ensuring a stable flow of auctions. A predictable project pipeline will allow investors to develop a sustainable local supply industry and reduce cost of future RES deployment in Ukraine.
2. It enables a RES share of above 20% in 2025 – which is better aligned with the political goal of increasing the RES share in the future.
3. The higher share of wind quotas reduces system cost.
4. The requirements for additional flexibility (3 – 3.5 GW by 2023) compared to a system without any new quotas are limited – while keeping supply-security at high levels. But reducing forecast errors and making the system even more flexible would allow to reduce coal generation markedly.

Table 1: Best case scenario

		2020	2021	2022	2023	2024
Wind	MW	135	200	200	270	270
Solar	MW	30	45	45	60	60
Biogas/-mass	MW	20	30	30	40	40
Small hydro	MW	10	15	15	20	20
Total	**MW**	**195**	**290**	**290**	**390**	**390**
Total 2020 - 2024	MW	**1555**				

1 Introduction

According to the renewable energy law of Ukraine, feed-in contracts for new renewables (RES) installations are allocated in auctions. Each year a predetermined amount of capacities for each technology – the so-called quota – is put up for auctioning. These RES quotas for 2020 – 2024 have to be determined in December 2019. This includes quotas for auctions of wind, solar and other RES capacities.

In the following, we propose technology-specific quotas for new RES installations until 2025.

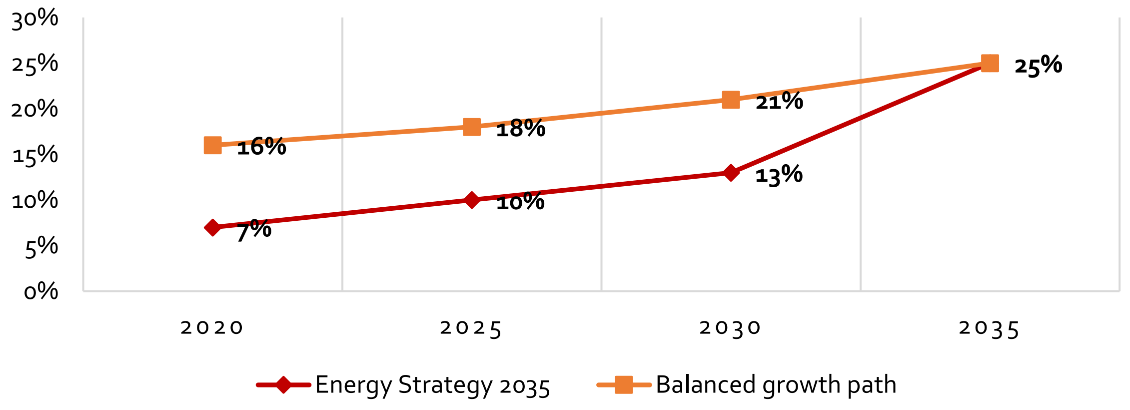
For determining the quotas, we used the Low Carbon Ukraine Optimal Dispatch Model (V6.0) that allows for analysing economically and technologically optimal investment decisions. We take into account the mandatory minimum shares for each technology (15% from total annual quota size for RES) as well as typical time frames for construction of renewable capacities.

We develop four scenarios of RES quotas that differ in system characteristics such as reserve requirements, the possibility of RES curtailment and additional flexibility (e.g., through fast-responding generation capacities). Moreover, we account for already signed pre-PPAs[1] for RES projects.

2 Methodology

We are following an optimisation approach, identifying the cost-optimal installation of wind, solar, biogas and small hydro capacities to fulfil a 2025 RES target. The assumptions on RES targets are fundamental for the resulting quotas: The higher the RES target (share in electricity generation, incl. big hydro), the higher the quotas. We decided to use the RES target of the Energy Strategy of Ukraine as an anchor point – 25% in 2035. However, the Energy Strategy target trajectory for reaching 25% in 2035 is problematic for two reasons: First, its original target share of 7% in 2020 is likely to be exceeded by the reality of RES deployment. Second, the Energy Strategy trajectory implies an exponential RES surge from 2030 until 2035, which could put the system under heavy stress. We hence developed a balanced growth path that (1) starts with the expected RES share of end 2020 – based on Ukrenergo capacity estimates – and (2) allows for a smoother and more linear development of RES in Ukraine. This balanced trajectory gives a RES target of 18% in 2025, which we use in scenarios 1,2 and 3. In scenario 4 we depict results for a higher RES target of 20%.

Figure 1: RES share (incl. big hydro) trajectories until 2035



Source: Ukrenergo, own calculations

1 Pre-PPAs are contracts based on the legacy renewables support system that allow investors to receive generous feed-in tariffs for the contracted capacities.

Key assumptions

Total generation in 2025 sums up to 157 TWh (excluding exports), which is between the upper and lower bound presented in "Звіт з оцінки відповідності (достатності) генеруючих потужностей" by Ukrenergo in 2019. We exclude exports from the analysis because they overestimate the system's flexibility. For imports we assume a capacity of 1.2 GW, which can be curtailed by the TSO.

Nuclear power plants (NPPs) are allowed to operate in the range between 6 GW and 12 GW, with results indicating that NPP generation in summer is lower.

We deduce quotas for 2020-2024 using the following approach:

- Initially installed RES capacities are set as end of 2020 capacities for all scenarios. For 2020 we assume solar capacities at 5.7 GW, wind capacities at 2.5 GW, biofuel capacities at 140 MW and small hydro at 100 MW. For scenario 3 and 4 we assume that 3 GW of RES capacities for which pre-PPAs will be signed until end 2019 will actually be commissioned. Given initial capacities for each scenario, we determine the optimal investment decision and hence new wind, solar, and other RES installations that are required to fulfil the respective RES targets.
- The difference between initially installed capacities in 2020 and optimal capacities for 2025 gives quotas for the years 2020-2024. Due to a time lag of 2 years between the auctions and the start of operation we assume that only quotas until first quarter of 2023 will affect the 2025 RES generation.

With RES capacities at 2020 levels, sufficient operating reserves to balance RES fluctuations are crucial. In scenarios 2, 3 and 4, operating reserves do not take the fixed values given in the current grid code. We argue that reserves based on the current grid code (scenario 1) would not be sufficient to balance the deviations of RES electricity generation from their forecasted values with RES capacities at 2020 levels. The current grid code hence underestimates future reserve requirements.

We therefore determine the operating reserves for each hour of system operation such that the reserves would allow to balance the deviations of actual RES electricity generation from their forecasted values with almost 100% certainty. Hence, high RES forecast errors lead to a large operating reserve that needs to be "online". With this conservative sizing of reserves, system operation would be safe with the new RES installations given below.

The optimisation model requires several assumptions – all of them affect the outcome to a different extent. These assumptions encompass cost parameters, technological parameters related to conventional capacities and capacity factors. Those are made transparent and we highlight the qualitative effects that changes in assumptions might have on model results (see Annex).

Quota scenarios

All four scenarios are based on the RES capacities that will become operational by the end of 2020, not including pre-PPA projects. Figures for expected RES capacities end 2020 are based on Ukrenergo estimates. Furthermore, in scenario 3 and 4 we assume that 3 GW of RES pre-PPA projects signed until end 2019 will be commissioned until end 2024.

Table 2: Scenario inputs – Installed RES capacities

Scenario		"Baseline"	"Introducing dynamic reserve sizing"	"Accounting for pre-PPAs and adding flexibility"	"20% RES share"
Scenario nr.		1	2	3	4
Installed capacity end 2020					
Wind	MW	2,500			
Solar	MW	5,660			
Biogas/-mass	MW	140			
Small hydro	MW	100			
Pre-PPAs coming in operation until end 2024					
Wind	MW	0		1,000	
Solar	MW	0		2,000	
Biogas/-mass	MW	0			
Small hydro	MW	0			

Source: Ukrenergo

Scenario 1 is the baseline scenario and assumes reserve sizing according to the current grid code. The current power plant park is modelled, i.e. no additional flexibility is installed. Curtailment of RES is not allowed.

Scenario 2 assumes a dynamic sizing of reserves (see Key assumptions above) based on a RES forecast error with a standard deviation of 40%. Curtailment is not allowed, and flexible generation is not added.

Scenario 3 allows for curtailment and assumes an improved, i.e. smaller, RES forecast error with a standard deviation 30%. Scenario 3 assumes that 3 GW of the pre-PPA projects which will be signed by the end of 2019 will eventually be realised. In this scenario, the optimal amount of additional flexibility options, such as gas peakers, is determined by the model.

Scenario 4 mirrors scenario 3 but sets a more ambitious 20% RES target in 2025, thus allowing to both to assimilate the large pipeline of pre-PPA projects and to set meaningful quotas while keeping investment into flexible generation at a moderate level.

Table 3: Scenario inputs – Assumptions

Scenario	"Baseline"	"Introducing dynamic reserve sizing"	"Accounting for pre-PPAs and adding flexibility"	"20% RES share"
Reserve sizing	Fixed (grid code)	Dynamic	Dynamic	Dynamic
Forecast error standard deviation – Wind and solar	-	40%	30%	30%
Curtailment allowed?	No	No	Yes	Yes
Optimization of additional flexibility options	No	No	Yes	Yes
RES target	18%	18%	18%	20%

3 Results

3.1 Aggregate outputs

The following table gives aggregate quotas and summary statistics for the four scenarios.

Table 4: Aggregate outputs

Scenario		"Baseline"	"Introducing dynamic reserve sizing"	"Accounting for pre-PPAs and adding flexibility"	"20% RES share"
Scenario nr.		1	2	3	4
Total quotas 2020 - 2024					
Total quotas – Wind	MW	1,760	2,935	0	1,075
Total quotas – Solar	MW	380	630	0	240
Total quotas – Biogas/mass	MW	260	420	0	160
Total quotas – Small hydro	MW	125	205	0	80
Generation shares 2025					
Nuclear PP	%	58%	39%	58%	54%
Thermal PP (including CHP)	%	24%	43%	24%	26%
Wind PP	%	7%	9%	7%	8%
Solar PP	%	5%	5%	7%	7%
Biogas/-mass PP	%	1%	2%	1%	1%
Small hydro	%	1%	1%	0%	0%
Big hydro	%	4%	1%	4%	4%
Further indicators					
RES curtailment	%	0	0	4%	7%
Required additional flexibility options (e.g. gas peakers)	GW	0	0	3.3	3.4
Total GHG emissions	Mt CO_2eq	30	62	31	35
GHG per MWh	kg / MWh	209	423	211	238
CAPEX p.a.	EUR/MWh	2.1	3.4	8.0	9.3
Variable costs	EUR/MWh	26.2	28.5	26.1	25.8
Generation costs (variable + investments)	**EUR/MWh**	**28.2**	**31.9**	**34.2**	**35.1**
Total investment 2021 - 2025	bn EUR	2.6	4.3	8.1	9.9
Number of hours with probability of reserve insufficiencies > 10%	hours	114	0	0	0
Capacity factor NPP	%	76%	51%	75%	70%
Capacity factor TPP	%	22%	44%	22%	25%
Capacity factor wind	%	36%			
Capacity factor solar	%	16%			

3.2 Quota allocation scenario results

In the following, we present annual RES quotas until 2024 for the four scenarios and discuss their results in more detail. We argue that it is beneficial to start with lower quotas for 2020 and to set higher quotas for the years 2021-24. This allows authorities and investors to take advantage of a learning effect and moreover allows for an improvement of RES forecasts, e.g. through a stricter enforcement of imbalance penalties.

We assume a time lag of 2 years from auction to commissioning of a RES plant. Hence only quotas before spring 2023 will affect the RES generation in 2025. We extrapolate subsequent 2023 and 2024 figures based on 2022 quotas.

3.2.1 Scenario 1 – "Baseline"

Table 5: Quota allocation 2020 – 2024 under scenario 1

"Baseline"		**2020**	**2021**	**2022**	**2023**	**2024**
Wind	MW	220	330	330	440	440
Solar	MW	50	70	70	95	95
Biogas/-mass	MW	30	50	50	65	65
Small hydro	MW	15	25	25	30	30
Total	**MW**	**315**	**475**	**475**	**630**	**630**
Total 2020 - 2024	MW	**2525**				

Scenario 1 allows reaching the 18% RES target without curtailment and additional flexibility. Since reserve requirement follow the current grid code, new RES imply only a modest increase in balancing needs. The thermal generation share hence remains low and nuclear plants can operate at close to full capacity. Hence, total emissions are reduced. Quotas indicate that a higher share of wind is economically preferable from a system cost perspective. This is due to the lower relative investment costs (per MWh generation) and lower fluctuations compared to solar.

This seemingly ideal scenario, however, **has one fundamental drawback:** operational reserves based on the outdated grid code. In our view, fixing reserves throughout the day at relatively low levels implies a significant threat to system security. This especially holds during noon hours, when total RES generation peaks. If it was not for pump hydro plants to consume the noon RES generation peak, we might have already experienced critical events in 2019.

We estimate that with operational reserves according to the current grid code, the probability that upwards reserves would not be able to balance downward deviations of RES generation from their forecasts would be at least 10% during 114 hours in 2025.

We hence argue that a dynamic and hourly sizing of reserves should be introduced, taking into account RES forecast errors and expected RES generation.

3.2.2 *Scenario 2 – "Introducing dynamic reserve sizing"*

Scenario 2 introduces dynamic hourly reserve sizing. This approach to determine adequate operating reserves is widely used in electricity system modelling (see e.g. Mark O'Malley 2005, or Zhou etal., 2016). Based on given RES forecast errors, it allows determining operational reserves that are able to balance deviations of RES generation from their expected values with a given certainty. We calibrated reserves such that in each hour, they are able to successfully balance RES forecast errors with 99.9% certainty.

This approach to reserve sizing is unquestionably more conservative and safer than the current grid code. For example, reserve requirements during noon hours (based on 40% forecast error and 99.9% risk aversion) can amount to 5 GW. These high requirements for reserves moreover lead to big hydro plants generating less than possible in order to provide sufficient leeway for up-and downwards balancing.

Scenario 2 thus serves as a good example for the so-called green-coal paradox – high RES shares leading to high balancing needs (provided by coal plants), reducing nuclear generation and hence resulting in high GHG emissions and operational costs.

Although reserve sizing is more conservative, total quotas are higher for scenario 2. This, however, is only possible because big hydro plants massively contribute to the operational reserve and thus reduce their dispatched output. As indicated in Table 4, the big hydro generation share decreases from 4% to 1% . Moreover, since variable wind and solar generation imply balancing needs, the model chooses a higher share of biogas/-mass quotas, which can operate in stable base load.

Table 6: Quota allocation 2020 – 2024 under scenario 2

"Introducing dynamic reserve sizing"		2020	2021	2022	2023	2024
Wind	MW	365	550	550	735	735
Solar	MW	80	120	120	155	155
Biogas/-mass	MW	50	80	80	105	105
Small hydro	MW	25	40	40	50	50
Total	**MW**	**520**	**790**	**790**	**1045**	**1045**
Total 2020 - 2024	MW	**4190**				

3.2.3 *Scenario 3 – "Accounting for pre-PPAs and adding flexibility"*

Our third scenario introduces four important changes: First, curtailment of RES in the dispatch process is now allowed. In fact, results show that this flexibility option is indeed being used, as 4% of potential RES generation is curtailed in the optimal dispatch we calculate.

Second, the scenario assumes that wind and solar forecast errors are improved from 40 to 30%. Third, the scenario allows for adding flexibility, e.g. by building gas peakers.

Fourth, this scenario accounts for the RES project which have not yet been commissioned but for which pre-PPAs have already been signed or will be signed by the end of 2019. Ukrenergo states these pre-PPA projects to amount to almost 4 GW. Assuming that 3 GW of these projects are realised, 3 GW were subtracted from RES quotas (around 1 GW of wind and 2 GW of solar) in scenario 3. If these pre-PPAs become operational, the system requires 3.3 GW of upward flexibility.

With these pre-PPAs projects, RES generate approx. 27 TWh in 2025, which implies a 18% share in total generation. Hence no new installations are required and quotas are zero.

Scenario 3 moreover shows that with an investment of around EUR 4.5 bln into new flexibility – gas peakers in this case – annual GHG emissions can be reduced from 62 to 31 Mt[2].

3.2.4 *Scenario 4 – "20% RES share"*

Given the high amount of pre-PPAs in the pipeline we argue for considering a fourth scenario that on the one hand allows the implementation of ca. 50% of these pre-PPAs and on the other hand allows to set meaningful quotas. We set a higher RES target in 2025 of 20% that allows for setting quotas of approx. 1.6 GW of RES until 2025.

Ensuring a stable flow of auctions would help to develop a sustainable local RES supply industry and provide investment security for RES producers. A 20% RES share is moreover better aligned with Ukraine's political goal of further increasing RES shares in the future.

Total investments (including pre-PPAs and flexibility options) sum up to EUR 10 bln until 2025. Compared to scenario 3, only 100 MW of additional flexibility is required. Emissions are higher in scenario 4 compared to 3 due to the fact that using existing coal plants as reserves is cheaper than building new gas peakers. This can be resolved by adding flexibility options not only on the generation side, e.g. demand response and international trade.

Table 7: Quota allocation 2020 – 2024 under scenario 4

"20% RES share"		2020	2021	2022	2023	2024
Wind	MW	135	200	200	270	270
Solar	MW	30	45	45	60	60
Biogas/-mass	MW	20	30	30	40	40
Small hydro	MW	10	15	15	20	20
Total	**MW**	**195**	**290**	**290**	**390**	**390**
Total 2020 - 2024	MW	1555				

[2] For a lifetime of 20 years that would be an implicit carbon price of 12 €/t.

3.3 Additional findings and constraints

1.] **Forecast errors in Ukraine are very high.** As long as the **forecast error** cannot **be reduced significantly**, system costs will increase dramatically with increasing RES shares because it would require, either the installation of flexible power plants, energy storage systems or increased curtailment.

2.] We argue that the relative **share of wind electricity generation** (compared to that of solar) **has to grow**. This is mainly due to the large difference between night and mid-day solar electricity generation that results in high balancing needs.

3.] Increasing forecast errors and no RES curtailment or additional flexibility options require **much higher shares of biogas** to meet the RES targets. Biogas and biomass would then provide baseload generation.

4.] Smaller forecast errors **increase the optimal solar share** since solar has lower investment costs per MWh of generated electricity.

5.] Allowing flexible **imports** can serve as another flexibility option and could allow to integrate higher RES shares. This means that ENTSO-E integration should be a top priority, and should be achieved as soon as possible.

4 Annex

4.1 Sensitivity to model parameters

This section focuses on model parameters that are critical for determining 2025 quotas and gives a qualitative sensitivity analysis on model results.

Capital cost

The model follows an optimisation approach that minimises aggregate system costs. Since determining quota means installating new RES capacities, RES investment cost (CAPEX) are part of the objective function and minimised by the model.

Obviously, the **relative costs** of the new RES types are crucial for determining which RES technology is preferred. The higher the investment cost per MW for a specific RES technology, the lower their aggregated installed capacity. E.g., higher capital cost for wind would lead to a lower resulting wind share.

Investment costs per MW for new RES installations are the same for all scenarios. Costs for wind and solar were deducted from investments in 2018 and 2019 in Ukraine (see Table A 1).

Variable generation cost

Relative differences in fuel cost (marginal generation costs) determine whether a technology is more or less used than others. We run all scenarios with the same set of marginal generation costs following Lazard (2019) (see Table A2).

Renewable capacity factors

Capacity factors – i.e. the percentage utilisation of the plant's nominal capacity – determine the revenue per MWh generated by a RES technology. The higher the capacity factor, the lower the investment per generated MWh. We use average hourly capacity factors based on wind speed and solar irradiation for each TSO region, provided by Ninja Renewables. We aggregate 2018 capacity factors for three locations in each region.

Operation of nuclear plants

The capacity range in which NPP are allowed to operate significantly affects the RES integration potential. The green-coal paradox describes a situation where in a system with high must-run obligations for conventional generators, rising RES shares lead to nuclear units being shut down. It holds that the higher the forecast errors, the lower the minimal generation of NPPs if curtailment is not allowed.

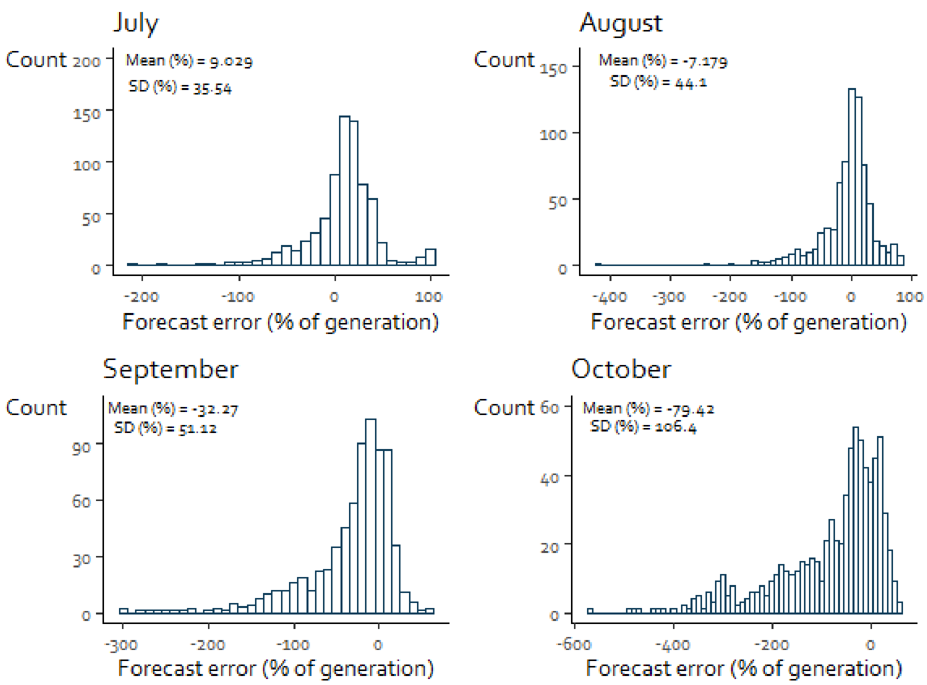
Forecast errors

With dynamic reserve sizing (scenarios 2 and 3), higher forecast errors of wind and solar generation imply higher reserve requirements in the electricity system.

An analysis of RES forecast figures from summer 2019 indicates a standard deviation of approx. 70%. Furthermore, forecast errors are biased: The expected generation is structurally over-estimated. The forecast error mean is -27% (see Figure A).

If no solution to this problem is found, new RES installations will require additional flexibility options before 2025 if targets should be met. Otherwise, nuclear generation would have to be significantly reduced, intensifying the green-coal paradox in Ukraine.

Figure A 1: RES- forecast error distributions Ukraine July – October 2019



Flexibility options

Each flexibility option supports the electricity system in handling the inherent fluctuations of RES. As long as forecasts cannot precisely determine the RES generation for subsequent days, the system has to provide higher reserve through balancing capacities.

As discussed in previous publications, allowing **curtailment** allows to integrate higher shares of flexible RES in the system.

Gas peakers and batteries are flexibility options that are typically used as operating reserves. Gas peakers primarily provide up-reserves and kick in if the actual RES generation is lower than expected (or if electricity demand is higher than expected). Batteries, on the other hand, typically provide both, up- and down-reserves.

Further options for balancing RES fluctuations such as **demand response**, **grid** expansion and integration into **ENTSO-E** will boost RES integration in the future.

4.2 Additional model parameters

Table A 1. Investment parameters

Type	EUR/MW	Life time	Interest rate
Wind	1,300,000*	25	12%
Solar	1,100,000*	25	12%
Biogas / Biomass	3,300,000*	30	12%

* Investments in EUR/MW according to Ukrainian 2018/19 projects (Eurasia Network (2019), Renewables Now (2018)) and international literature

Table A 2: Capacities and variable costs

Type	Installed capacity end 2020, GW	Variable costs, EUR/MW*
NPP	13.8	30
TPP	15.8	40
Big Hydro	4.6	0
Wind	2.5	0
Solar	5.66	0
Biogas / Biomass	0.238	60
Pump	3.3	0
Gas peakers	0	50
Import (transfer capacity)	1.2	50

* Variable costs based on Lazard 2019

4.3 One-Year day-ahead run based on scenario 4

The following figures show the results of a day-ahead optimization for one year (2025) based on Scenario 4. Total demand (including exports) is set at 164 TWh, while exports are not considered in the daily dispatch to avoid its use as a flexibility option.

The TPP (coal) generation in this run is 2 TWh lower than forecasted in the investment approach, since coal (and to a lower extent nuclear generation) crowds out imports, which are 5 TWh lower than forecasted. They sum up to only 1 TWh.

Renewable generation amounts to 20%, yet big hydro is operating below its potential, which is due to its use as a flexibility option.

Figure A 2: Generation shares & generation, scenario 4 – one-year day-ahead simulation

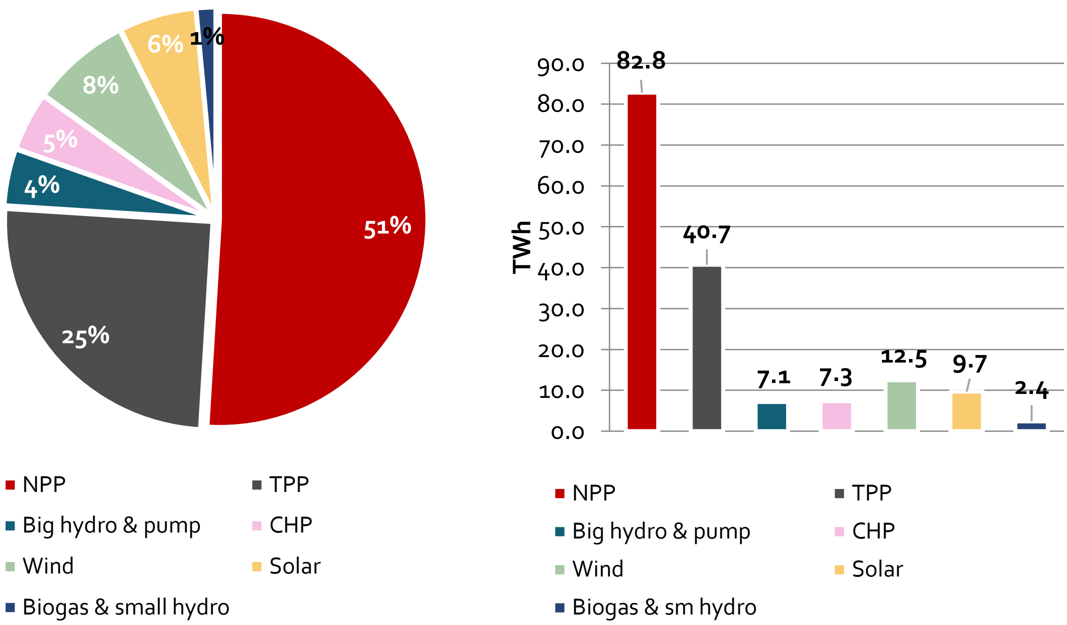
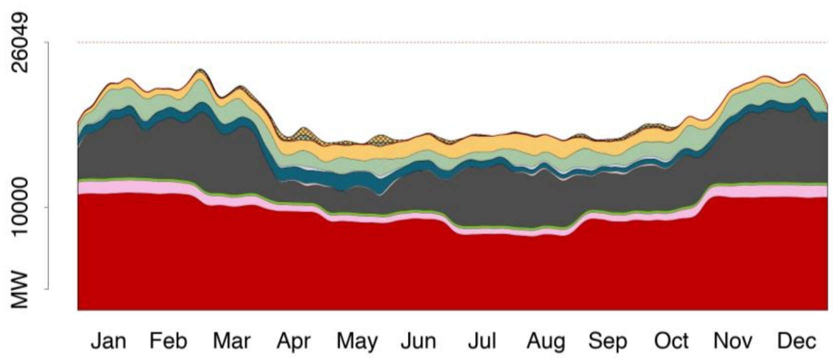
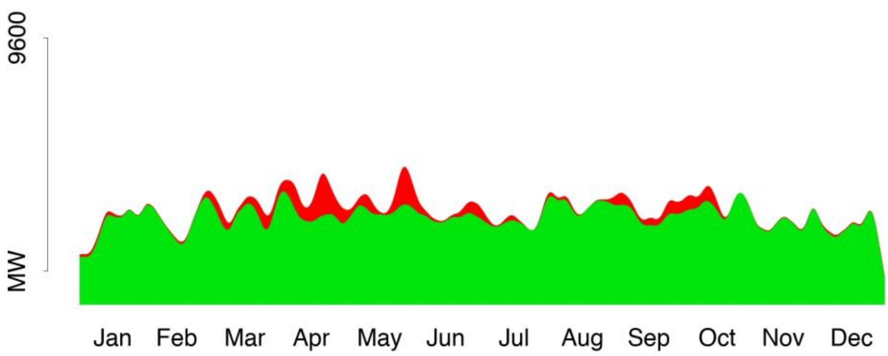


Figure A 3: One year generation, scenario 4 – one-year day-ahead simulation



Curtailment amounts to 7% of potential RES generation and takes place mostly in spring, with solar being curtailed more than wind (10% vs. 4%).

Figure A 4: Aggregate RES curtailment, scenario 4 – one-year day-ahead simulation



The aggregate GHG emission of electricity generation (excluding CHP) amounts to 41 Mt CO_2, which is 5.4 Mt higher than forecasted due to higher coal generation.

5 Literature

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