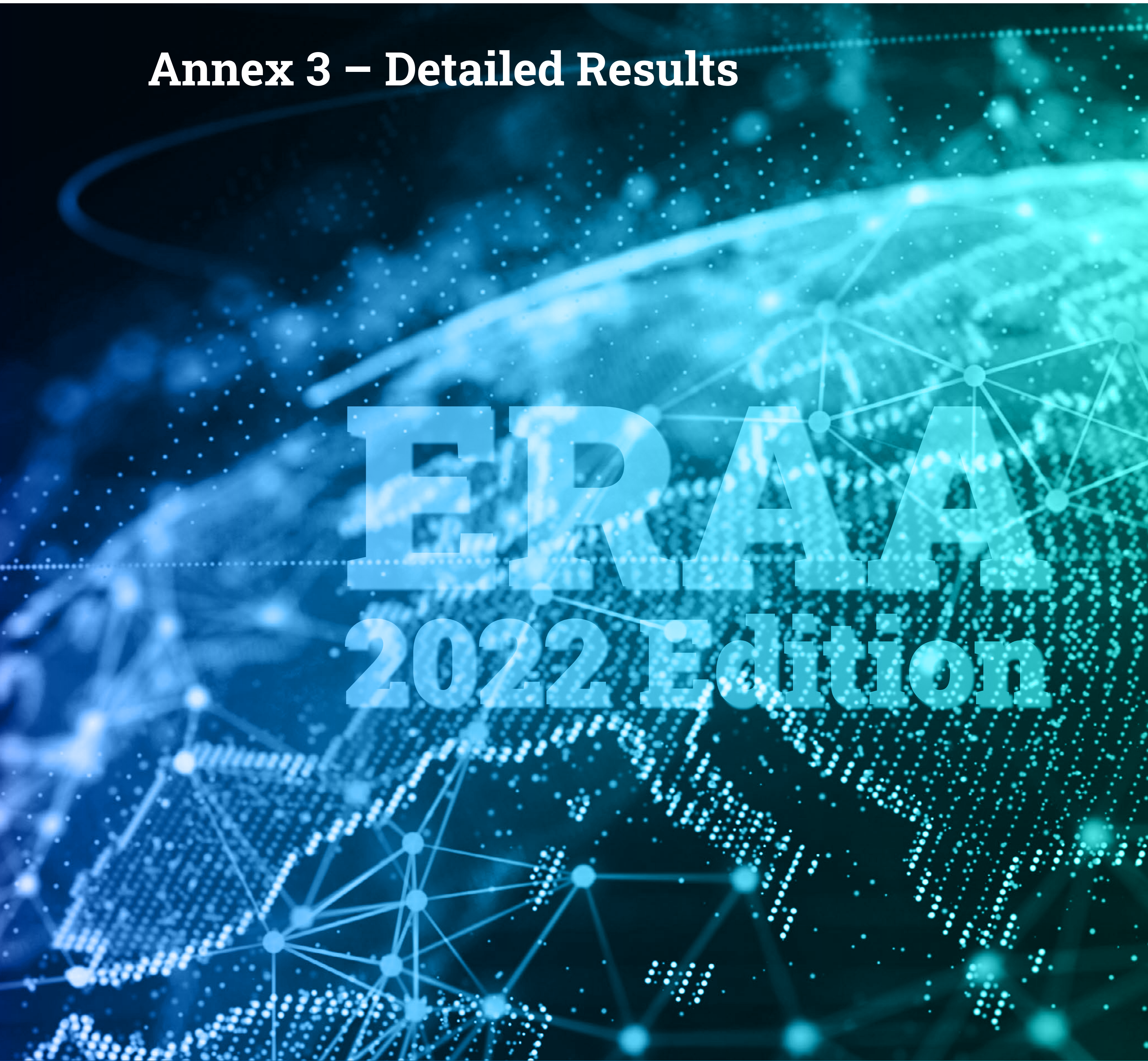
European Resource Adequacy Assessment

2022 Edition

Annex 3 – Detailed Results



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European Resource Adequacy Assessment 2022

Annex 3 – Detailed results

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1 Introduction

In this Annex, detailed tables and graphs aim to provide insights on the results for all the central reference scenarios. These results cannot be dissociated from the assumptions (cf. Annex 1) and the overall methodology followed in the European Resource Adequacy Assessment (ERAA) 2022 (cf. Annex 2). The presentation of results is organised per scenario and includes results from the single reference tool.

The results of each simulation include values of loss of load duration (LLD) and energy not served (ENS), which are aggregated in sets of LLDs and ENSs per bidding zone (BZ) and modelling tool. LLDs are expressed as the number of hours of the simulation's time horizon during which supply could not meet demand in a given BZ, whereas ENSs are expressed in GWh of unserved energy during the LLD hours. For each set of LLDs and ENSs, the mathematical expectation/average, the median/50th percentile and the 95th percentile value were derived. These values are defined as loss of load expectation (LOLE), expected energy not served (EENS), P50 LLD, P50 ENS, P95 LLD and P95 ENS, respectively[1]. In addition, the ratios between EENS and the annual demand by BZ were also calculated. Readers should refer to Annex 2 for more details on the calculation methodology and for mathematical descriptions of the above.

In addition, the results of some BZs are aggregated to the country level, namely:

- Danish BZs DKE1 and DKW1 are aggregated in DK00. Zone DKKF does not include any demand and is thus excluded from the country level aggregation.
- Irish BZs IE00 and UKNI are aggregated in I-SEM.
- Italian BZs ITCA, ITCN, ITCS, ITN1, ITS1, ITSA and ITSI are aggregated in IT00.
- Norwegian BZs NOS0, NOM1 and NON1 are aggregated in NO00.
- Swedish BZs SE01, SE02, SE03 and SE04 are aggregated in SE00.
- Zone DEKF does not include any demand, thus demand in Germany is reflected in DE00 alone.

For a geographical area with multiple nodes, ENS is calculated as the total ENS of all its nodes. Moreover, EENS is the mathematical average of the ENS calculated over the total number of Monte Carlo (MC) sample/simulation years. Similarly, for a geographical area with multiple nodes, LLD is the number of hours during which at least one node in the area experiences ENS during a single MC sample/simulation year, whereas LOLE is the mathematical average of the LLD over the total number of MC sample/simulation years.

2 Calculated inputs/Intermediary Inputs

2.1 Flow-based domains

For the ERAA 2022, the clustering process resulted in 4 clusters, and therefore 4 flow-based (FB) domains. For both the winter and summer hours, 2 clusters were identified. For both sets of clusters, a model determined the allocation of domains to specific hours. The FB domain results therefore consist of a set of 4 domains and the allocation key of those domains to each hour of all climate years (CYs) ran in the ERAA FB market

[1]For a set of 100 calculated values, the 95th percentile (often abbreviated as P95) represents the value that is greater than or equal to 95% and lower than or equal to 5% of all values contained in the set. The 50th percentile is calculated accordingly.

simulations. As described in Annex 2, the 4 timestamps for which the representative FB domains were calculated are the following. The year refers to the CY that was used as for the reference calculation.

Table 1: Initial market model timestamps

Timestamp #	Timestamp
1	1988-09-14 23:00
2	2014-06-14 19:00
3	2014-10-27 04:00
4	2014-11-09 13:00

In the ERAA 2022, all borders between CORE and non-CORE BZs are modelled as advanced hybrid coupling (AHC) and there is a single evolved flow-based (EFB) element, namely the Alegro DC link between Belgium and Germany. With 12 Core BZs, one EFB link and 29 AHC links, this brings the total amount of variables in the FB domain to 42. As this means that the FB domain has 42 dimensions, it is computationally impossible to compute full 2D projections of the FB domain. Instead, for visualisation purposes, it was necessary to select some relevant dimensions for each chosen projection. For the projections shown here, the impact of the AHC borders was fixed to the relevant border flows over these links from the reference case, so these are projections of the standard hybrid coupling FB model. Of course, this reduction is only applied for illustrational purposes and, in the adequacy simulation, all dimensions are considered in full and not fixed to any pre-determined value. The 2D projections of the FB domains for combinations of areas are shown in Figure 1.

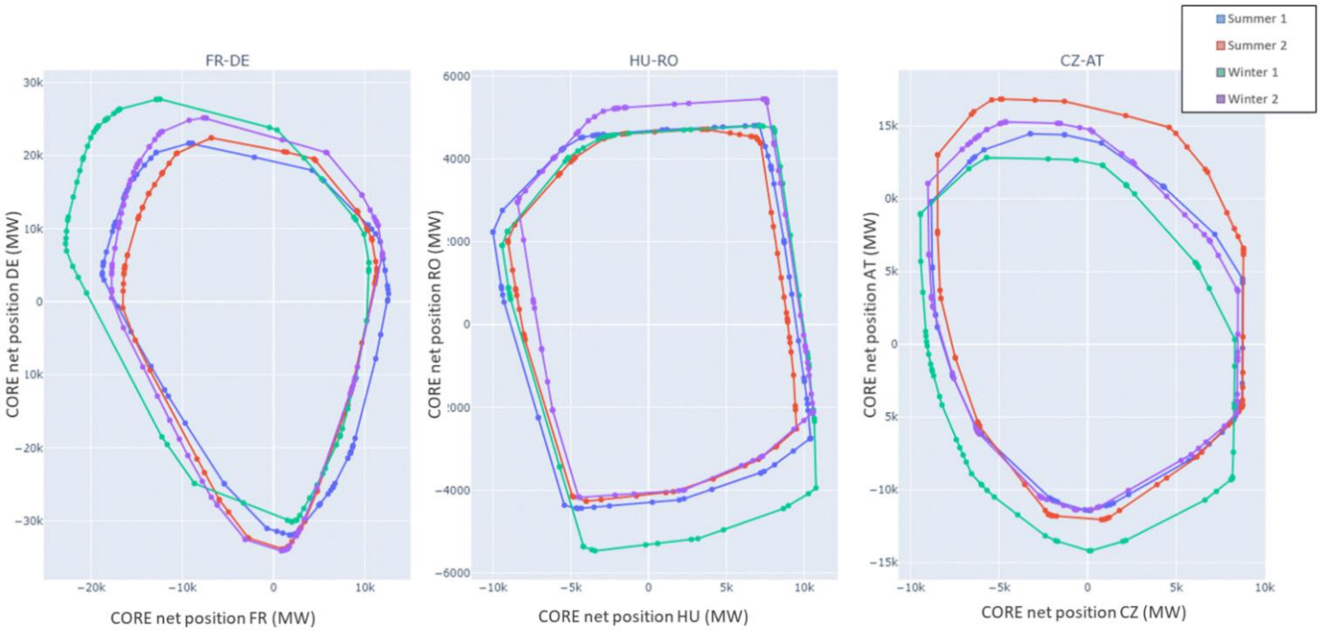


Figure 1: projections of FB domains

Although we may conclude that the forms of the domains are rather similar, the allowed shift in CORE net positions differs significantly. Whereas, for example, the domains summer 1, summer 2 and winter 2 are relatively similar for the net positions of the DE and FR BZs, the allowed import to the FR BZ is significantly bigger for the winter 1 domain. Moreover, as for these projections the exchanges on AHC borders have been fixed to their initial reference value, a change in the value of AHC exchanges can have a significant impact on the shape of the domains. Differences in FB domains lead to different market clearings depending on which of the FB domains is actually selected to be used on the market simulation model.

A second indicator to represent FB domains is the maximum theoretical import and export capacities of BZs as shown in Figure 2. These are the maximum Capacity Calculation Region (CCR) net positions of the BZs per FB domain. These values are calculated by finding the maximum CCR net position per BZ subject to the FB constraints. It should be noted that these values are more of a theoretical approach as for the calculation, the only target is to maximise export or import capacity for a single BZ. A second point is that for these calculations, the AHC borders were fixed to 0, so these are the maximum import and export capacities when disregarding the additional capacity that optimisation of these elements could add. Although they are therefore not a good indication of the actual expected exports or imports, they do enable comparison between different domains.

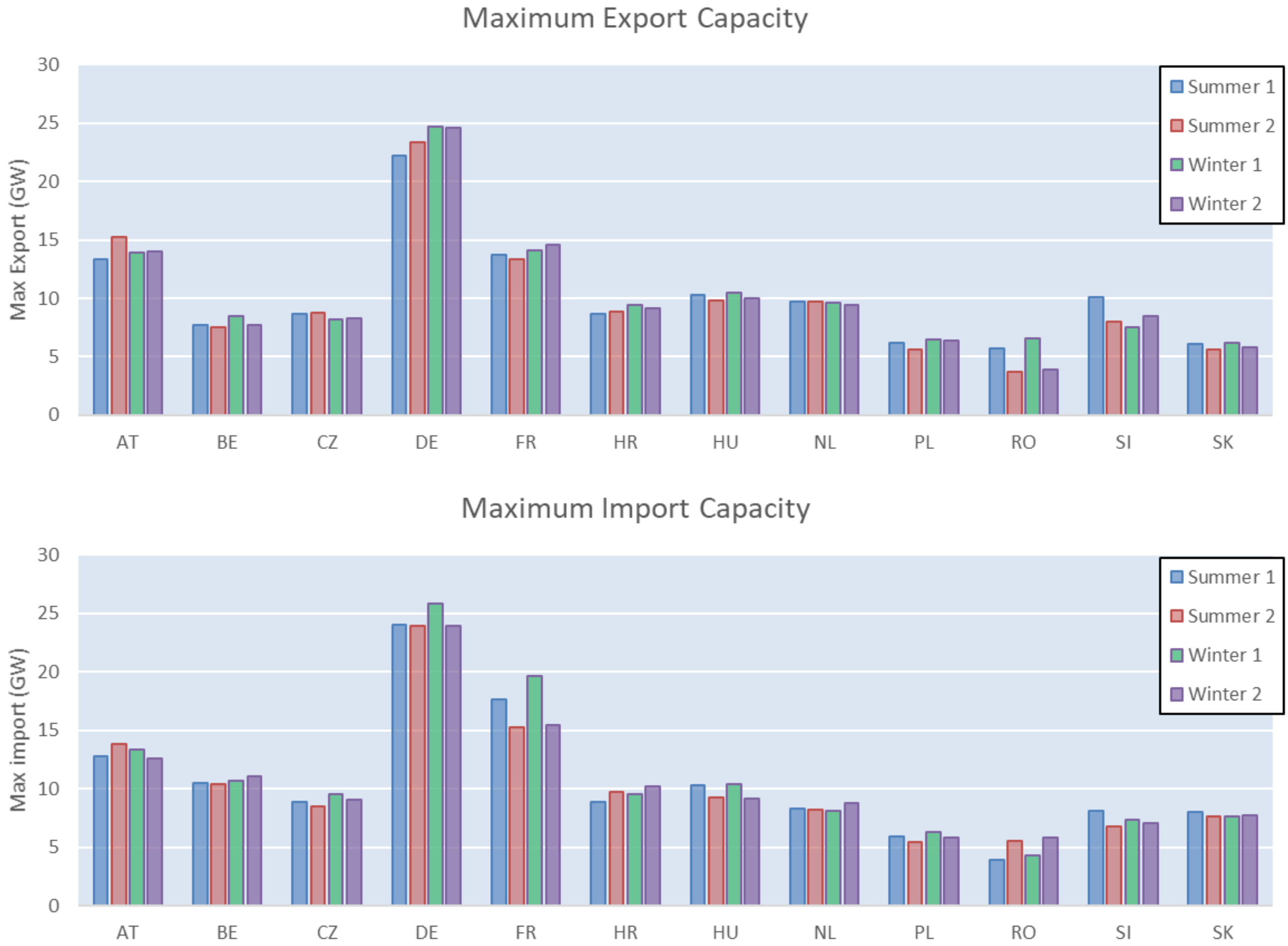


Figure 2: Theoretical maximum export and import capacities

2.2 Maintenance Profiles

As described in Annex 2, only thermal assets are subject to planned maintenance. The capacities are taken out of the market for maintenance during times of low risk of scarcity. Figure 3 shows the daily maintenance ratio profiles aggregated for thermal technologies in the ERAA explicit region for each of the target years (TYs).

As illustrated in Figure 3, the ratios of each TY are quite similar and the maximum ratio across all TYs is approximately 21% during the summer season, whereas the minimum ratio across all TYs is approximately 4% during the winter season.

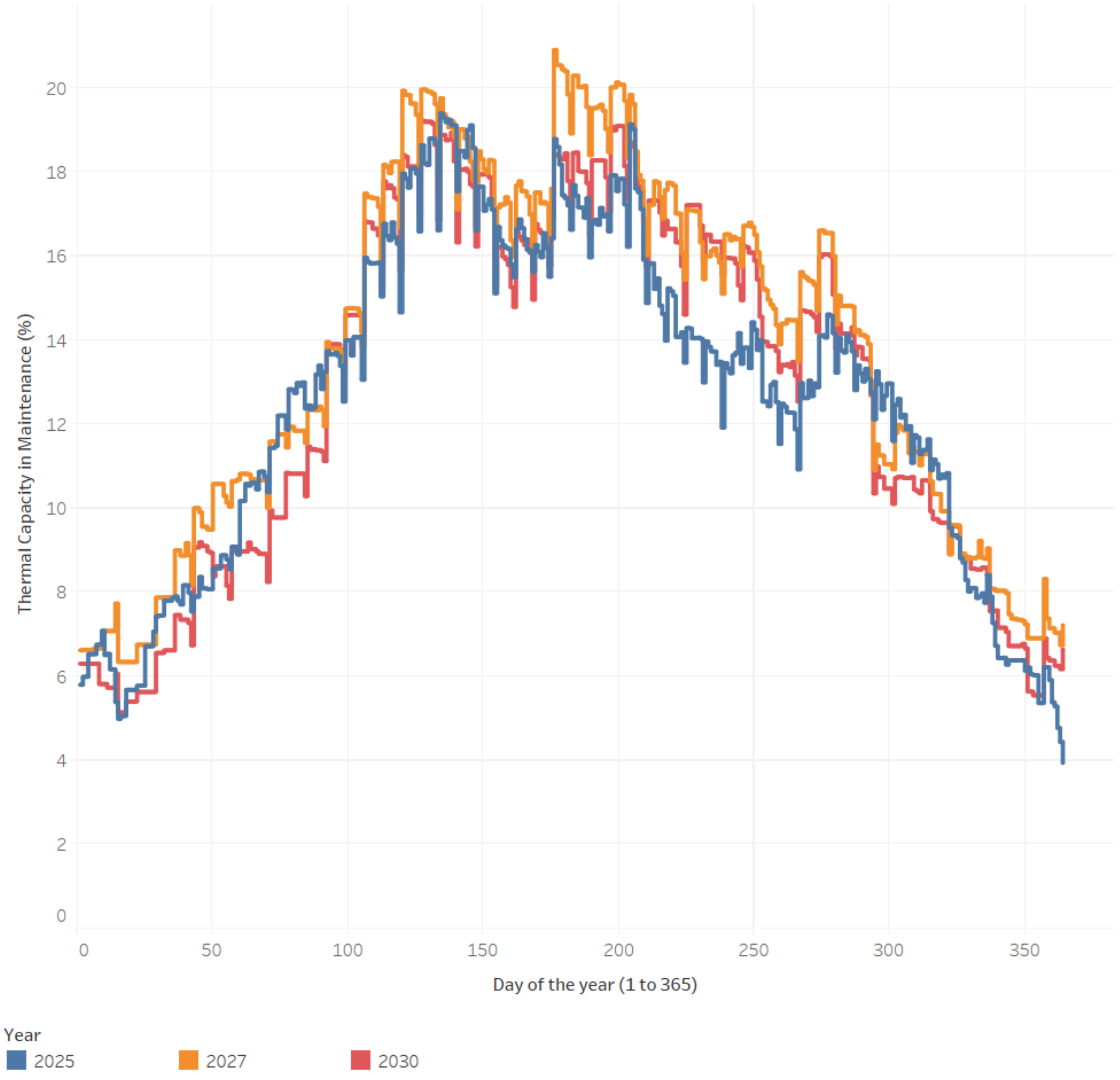


Figure 3: Thermal capacity maintenance ratio

2.3 Price caps

As a reminder from Annex 1 section 6.6, Table 2 below shows the price cap evolution used in the ERAA 2022.

Table 2: Price cap [€/MWh] per TY

2024	2025	2026	2027	2028	2029	2030
5 000	5 000	6 000	6 000	7 000	8 000	8 000

2.4 Representative climatic scenarios

As introduced in Annex 2, the methodology to identify 3 representative climatic scenarios was implemented on TY 2030 as more renewables are in present and thus have a larger impact on the EVA. As such CYs 1985, 1988 and 2003 were identified with probabilities of 0.028, 0.057, 0.914 respectively.

3 Central reference scenario without CM

3.1 EVA results

Table 3 presents the capacity change per decision variable, for each technology and future years (TYs and non-TYs) and also for the most affected BZs. As explained in annex 2 section 10.1.5, assumptions on the non-TY data were needed to carry out the EVA. The values in the table represent capacity differences with respect to the 'National Estimates' assumptions for each TY, i.e. if a certain capacity deemed non-viable reaches its expected decommissioning date, the non-viable capacity reported leaves out this capacity as from the TY of the expected decommissioning date. Detailed results per BZ are given in Table 4.

Gas technologies appear more likely to be decommissioned than lignite and hard coal, mostly because the fuel price assumption brings gas after coal in the merit order.

Table 3: Capacity change proposed by the EVA compared to the National Estimates scenario [MW] – Non-cumulative

Decision Variable	Technology	2024	2025	2026	2027	2028	2029	2030	Mostly affected BZ
Economic Commissioning	Battery	110	110	110	110	110	110	110	MT
	DSR	3270	3910	4340	4900	6430	6930	7260	SE, ES, NL, DE, DK, PT
	Gas	0	440	740	740	2970	9460	13950	DE, DK, IE, MT
Economic Life Extension	Gas	0	0	520	530	3560	3950	4110	DE, BE, DK
Economic Decommissioning	Coal	-6850	-9780	-10450	-10630	-11360	-11590	-13190	BG, PL, RO, BA, DE
	Gas	-53240	-50220	-54000	-57560	-52280	-48850	-48660	UK, DE, ES, GR, ITN, NL
	Other non-RES	-4410	-4250	-4120	-4630	-3550	-3330	-3240	DE, UK, HU, EE
	Other RES	-280	-280	-280	-810	-810	-600	-630	EE, FI, PL
Total		-61400	-60070	-63140	-67350	-54930	-43920	-40290	UK, DE, ES, ITN, PL, DK

Table 4: Capacity change proposed by EVA per BZ and decision variable [MW] – Non-cumulative

Node	Decision Variable	2024	2025	2026	2027	2028	2029	2030	Mostly affected technology
AL00	Decommissioning	0	-100	-100	-100	-100	-100	-100	Gas
AT00	Commissioning	0	0	0	150	160	190	190	DSR
AT00	Decommissioning	-1060	-1000	-1020	-950	-950	-950	-940	Gas, Other non-RES
BA00	Decommissioning	0	-1240	-1060	-1060	-1220	-1220	-1220	Coal
BE00	Decommissioning	-740	0	0	0	0	0	0	Gas
BE00	Life Extension	0	0	520	520	520	910	910	Gas
BG00	Decommissioning	-680	-2180	-2870	-2720	-2680	-3160	-3160	Coal, Gas
CH00	Decommissioning	0	0	0	0	0	0	0	N/A
CY00	Decommissioning	0	0	0	0	0	0	0	N/A
CZ00	Commissioning	0	0	0	70	70	70	70	DSR
CZ00	Decommissioning	0	0	0	0	0	0	0	N/A
DE00	Commissioning	0	0	40	40	3050	9540	10820	Gas, DSR
DE00	Decommissioning	-11220	-10810	-10030	-10030	-7170	-7160	-7010	Gas, Coal, Other non-RES
DE00	Life Extension	0	0	0	0	2970	2970	3120	Gas
DKE1	Commissioning	0	0	10	140	290	290	670	Gas, DSR
DKE1	Decommissioning	0	0	0	0	0	0	0	N/A
DKE1	Life Extension	0	0	0	0	50	50	50	Gas
DKW1	Commissioning	0	0	10	210	500	500	3250	Gas, DSR
DKW1	Decommissioning	-150	-150	-100	-100	-100	-100	-100	Gas
DKW1	Life Extension	0	0	0	10	20	20	30	Gas
EE00	Commissioning	0	0	0	0	0	0	130	DSR, Gas
EE00	Decommissioning	0	0	0	-660	-660	-660	-660	Other non-RES, Other RES
ES00	Commissioning	1000	1000	1000	1000	1000	1000	1000	DSR
ES00	Decommissioning	-9570	-10110	-9590	-9890	-9910	-9910	-9910	Gas (in 2025 540 MW of coal are also accounted)
FI00	Commissioning	120	120	120	120	120	120	120	DSR
FI00	Decommissioning	-210	-260	-210	-320	-320	-80	-80	Other RES, Coal, Gas
FR00	Decommissioning	0	0	0	0	0	0	0	N/A
GR00	Commissioning	0	20	20	20	20	20	20	DSR
GR00	Decommissioning	-1210	-1210	-1880	-2790	-2790	-2790	-4140	Gas
GR03	Commissioning	190	270	270	270	270	270	270	DSR
GR03	Decommissioning	-120	-410	-410	-410	-410	-410	-410	Other non-RES
HR00	Decommissioning	-1590	-1590	-1590	-1590	-1590	-1590	-1880	Gas, Other non-RES, Coal
HU00	Commissioning	20	20	20	20	20	60	60	DSR
HU00	Decommissioning	-2470	-2610	-2200	-2200	-2200	-2200	-2230	Gas, Other non-RES, Coal
IE00	Commissioning	0	340	540	540	540	540	540	Other non-RES, Gas
IE00	Decommissioning	-250	0	0	-340	-340	-340	-340	Other non-RES
ITCA	Commissioning	0	0	0	0	0	0	0	N/A
ITCA	Decommissioning	0	0	-850	-1030	-1030	-1030	-1030	Gas
ITCN	Commissioning	0	0	0	0	0	0	0	N/A
ITCN	Decommissioning	-170	-170	-170	-170	-170	-170	-170	Gas
ITCS	Commissioning	0	0	0	0	0	0	0	N/A
ITCS	Decommissioning	-700	-700	-3230	-3230	-3230	-3230	-4740	Gas

Node	Decision Variable	2024	2025	2026	2027	2028	2029	2030	Mostly affected technology
ITN1	Commissioning	0	0	0	0	0	0	0	N/A
ITN1	Decommissioning	-4850	-4850	-5380	-6330	-6330	-6330	-6680	Gas
ITS1	Commissioning	0	0	0	0	0	0	0	N/A
ITS1	Decommissioning	-250	-250	-250	-250	-250	-250	-530	Gas
ITSA	Decommissioning	0	0	0	0	-300	-300	-510	Gas
ITSI	Commissioning	0	0	0	0	0	0	0	N/A
ITSI	Decommissioning	-150	-150	-150	-150	-360	-360	-360	Gas
LT00	Commissioning	0	0	0	0	0	0	120	DSR
LT00	Decommissioning	0	0	0	0	0	0	0	N/A
LUG1	Decommissioning	0	0	0	0	0	0	0	N/A
LV00	Commissioning	0	0	0	0	0	0	80	DSR
LV00	Decommissioning	-180	-180	-180	-180	-180	-180	-180	Gas
ME00	Decommissioning	0	0	0	-60	-230	-230	-230	Coal
MK00	Decommissioning	-20	-20	-20	-20	-20	-20	-20	Gas
MT00	Commissioning	110	210	310	310	310	310	310	Gas, Battery
MT00	Decommissioning	0	0	0	0	0	0	0	N/A
NL00	Commissioning	230	290	640	650	650	910	960	DSR
NL00	Decommissioning	-3350	-2630	-2630	-1840	-1840	-1410	-1160	Coal
NOM1	Decommissioning	0	0	0	0	0	0	0	N/A
NON1	Decommissioning	0	0	0	0	0	0	0	N/A
NOS0	Decommissioning	0	0	0	0	0	0	0	N/A
PL00	Commissioning	0	0	0	0	0	0	30	Gas
PL00	Decommissioning	-3680	-3680	-6310	-6320	-6320	-6110	-6110	Coal, Lignite
PT00	Commissioning	0	250	270	270	570	570	570	DSR
PT00	Decommissioning	0	-210	-550	-550	-550	-550	-340	Gas
RO00	Commissioning	0	230	230	230	230	230	230	DSR
RO00	Decommissioning	-2280	-2080	-1190	-1330	-1440	-1440	-1570	Coal, Gas
RS00	Decommissioning	0	0	0	-370	-720	-720	-1530	Coal
SE01	Decommissioning	-90	-90	-90	-90	-90	-90	-90	Gas
SE02	Decommissioning	-50	-50	-50	-50	-50	-50	-50	Gas
SE03	Commissioning	750	750	750	750	750	750	750	DSR
SE03	Decommissioning	-310	-40	-40	-40	-40	-40	0	Gas
SE04	Commissioning	920	920	920	920	920	920	920	DSR
SI00	Commissioning	40	40	40	40	40	40	40	DSR
SI00	Decommissioning	-250	-250	-250	-240	-240	-240	-620	Coal, Gas
SK00	Commissioning	0	0	0	0	0	170	170	DSR
SK00	Decommissioning	-270	-270	-270	-270	-270	-270	-270	Gas
TR00	Decommissioning	0	0	0	0	0	0	0	N/A
UA02	Decommissioning	0	0	0	0	0	0	0	N/A
UK00	Decommissioning	-18230	-16580	-15450	-16980	-12930	-9730	-6380	Gas, Other non-RES
UKNI	Decommissioning	-680	-680	-730	-960	-960	-960	-960	Gas, Other non-RES

The EVA showed viable expansion of DSR capacities and life-extension possibilities. Gas expansion showed viable cases in the last target years and mainly for Germany. However, the mothballing/demothballing strategy did not show any viable case. A modelling reason can partially explain this behaviour. The mothballing decision is taken at each step of the EVA (see Annex 2, Section 11.1.7). A unit would only be mothballed if it is demothballed before the end of the same step, otherwise the unit would be economically decommissioned. However, although the mothballing decisions are taken at a yearly level, the steps length is a couple of years, so it leaves almost no flexibility for a unit to be mothballed then demothballed. Based on the assumption taken, the demothballing cost is heavy, hence mothballing is deemed a non-viable strategy when a unit is mothballed for only a couple of years.

As shown in Table 4, Germany also showed high gas decommissioning in the first years, however if the EVA had fewer steps (more years in each step) there would have been viable cases for mothballing in the first few years and consequently demothballing in the later years. A longer horizon would in general have a certain effect on the EVA results, avoiding permanent economic decommissioning in the years around 2025, as they will be needed in the system when the coal-fuelled generation is being phased-out in later years towards 2030.

The net effect of the EVA on the European mix is displayed Figure 4 and Figure 5 for the three TYs. In 2025, there is a net reduction of 50 GW of gas with an overall net reduction of 60 GW with regards to the 'National Estimates'. In 2030, this reduction is lessened to 40 GW net, with the economic commissioning of additional capacities as well as the extension of the lifetime of some units.

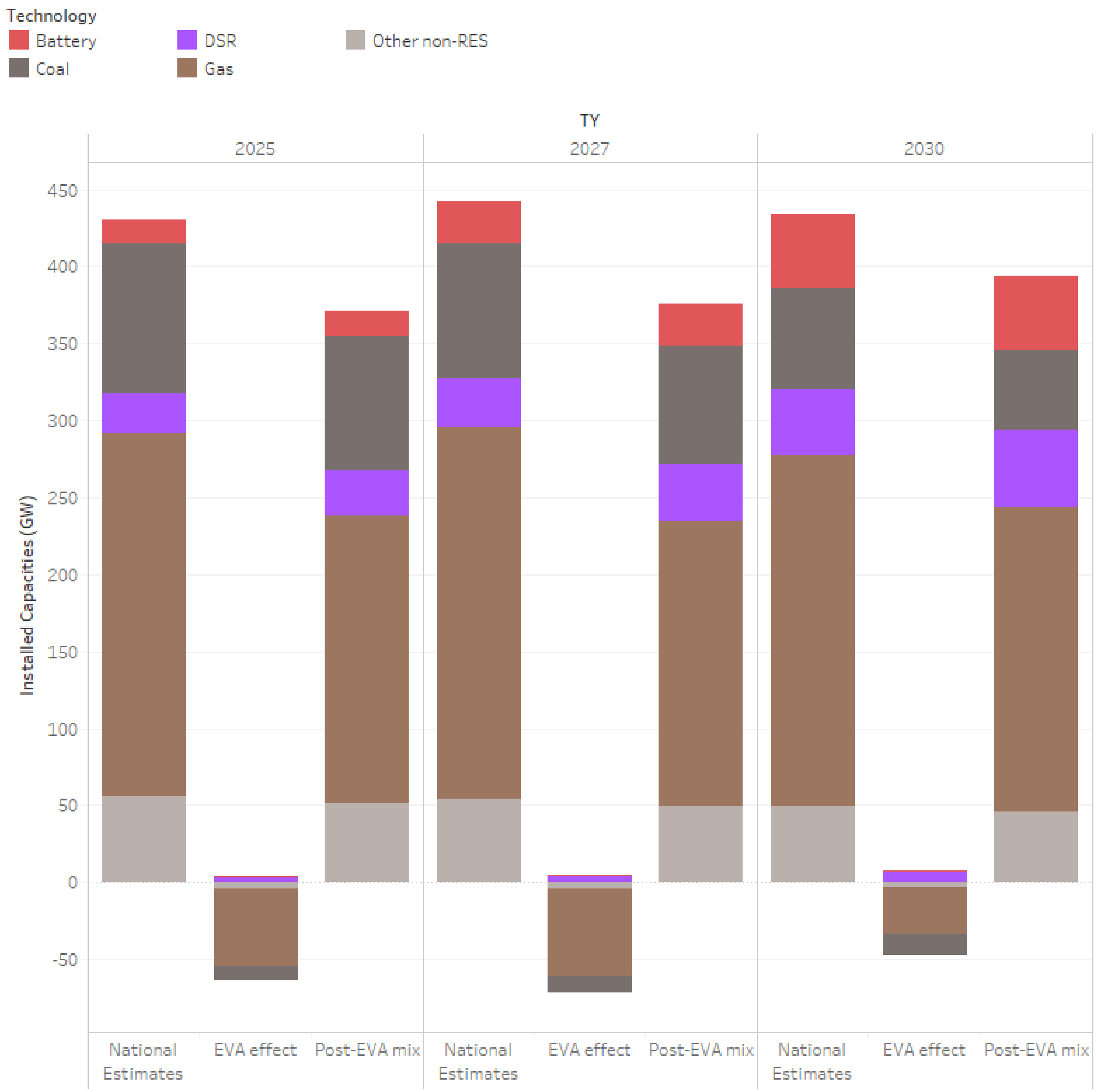


Figure 4: Net effect of the EVA on the European mix – focus on the technologies assessed

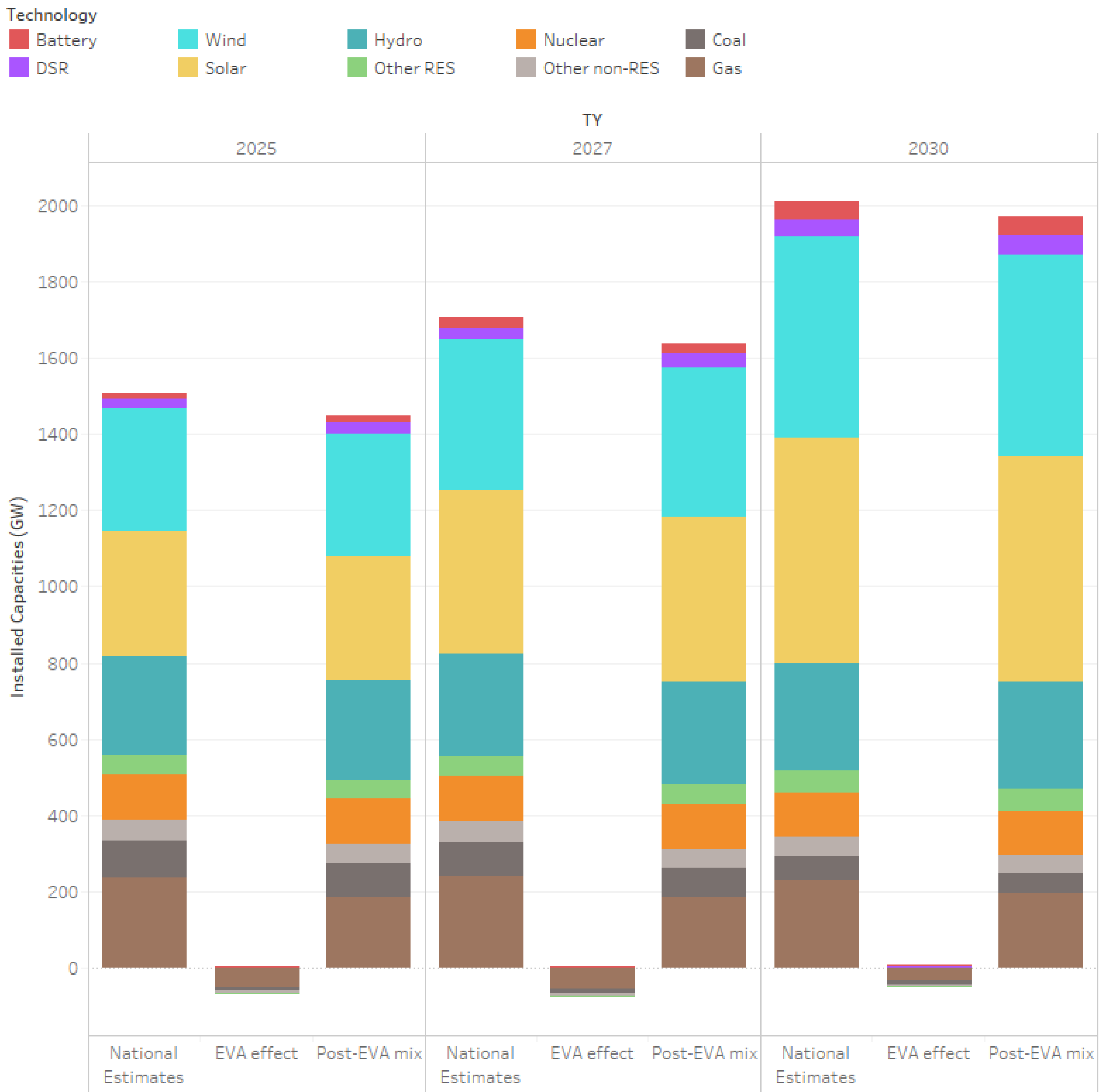


Figure 5: Net effect of the EVA on the European mix

3.2 Adequacy results

The following chapters give insights into the detailed results per study zone, as well as quantifications of the convergence of the model.

3.2.1 LOLE and EENS

The following tables include EENS and LOLE results per study zone for all scenarios as well as the 50th and 95th percentiles of ENS and LLD occurrences. 95th percentile occurrences can be interpreted as a '1-time-in-

20 years' occurrence and thus covers events with a lower likelihood but higher impact on adequacy. Results consider the activation of already approved out-of-market measures for Poland and Sweden[2].

Table 5: BZ LOLE (average) and LLD percentiles for the scenario without CM, for TY 2025

BZ	Without CM – TY 2025		
	Average [h/year]	P50 [h/year]	P95 [h/year]
AL00	0.4	0.0	3.0
AT00	1.5	0.0	6.0
BA00	3.5	0.0	9.0
BE00	6.5	0.0	31.0
BG00	0.1	0.0	0.0
CH00	0.0	0.0	0.0
CY00	0.0	0.0	0.0
CZ00	0.0	0.0	0.0
DE00	10.5	2.0	41.0
DKE1	7.4	0.5	29.0
DKW1	9.8	2.0	37.0
EE00	4.5	0.0	27.0
ES00	6.7	4.0	24.0
FI00	3.5	0.0	24.0
FR00	5.7	0.0	22.0
GR00	0.3	0.0	2.0
GR03	1.1	0.0	7.0
HR00	0.0	0.0	0.0
HU00	6.3	0.0	26.1
IE00	24.3	22.0	55.0
ITCA	0.0	0.0	0.0
ITCN	7.9	0.0	32.0
ITCS	0.7	0.0	1.0
ITN1	0.4	0.0	0.0
ITS1	0.0	0.0	0.0
ITSA	0.4	0.0	2.0
ITSI	0.0	0.0	0.0
LT00	3.8	0.0	28.0
LUG1	10.5	2.0	41.0
LV00	0.1	0.0	0.0
ME00	0.0	0.0	0.0
MK00	2.1	0.0	8.0

[2] The Central Reference Scenario Without CM accounts for CMs that already hold a CM contract granted in any previous auction of any existing or approved CM at the time of the assessment, including strategic reserves, which are relevant for Sweden and Poland in TY 2025.

BZ	Without CM – TY 2025		
	Average [h/year]	P50 [h/year]	P95 [h/year]
MT00	22.3	10.5	93.0
NL00	0.1	0.0	0.0
NOM1	0.0	0.0	0.0
NON1	0.0	0.0	0.0
NOS0	0.0	0.0	0.0
PL00[3]	0.0	0.0	0.0
PT00	0.0	0.0	0.0
RO00	1.7	0.0	5.0
RS00	2.9	0.0	8.0
SE01	0.0	0.0	0.0
SE02	0.0	0.0	0.0
SE03	1.9	0.0	14.0
SE04	2.0	0.0	15.0
SI00	1.0	0.0	3.0
SK00	0.0	0.0	0.0
TR00	0.6	0.0	4.0
UK00	5.1	2.0	19.0
UKNI	0.5	0.0	4.0

Table 6: Country LOLE (average) and LLD percentiles for the scenario without CM, for TY 2025

Country	Without CM – TY 2025		
	Average [h/year]	P50 [h/year]	P95 [h/year]
DK00	10.9	2.0	41.0
ISEM	24.6	22.0	57.0
IT00	8.2	1.0	32.0
LU00	10.5	2.0	41.0
NO00	0.0	0.0	0.0
SE00	2.2	0.0	15.0

[3] Practically speaking, there is no scenario without CM for Poland for the period up to and including 2026, as CM auctions have been already conducted for this period. Therefore, LOLE / EENS results for Poland in 2025 for the scenario without CM are lowered by the use of DSR contracted for this year.

Table 7: BZ EENS (average) and ENS percentiles for the scenario without CM, for TY 2025

BZ	Without CM – TY 2025		
	Average [GWh]	P50 [GWh]	Average [GWh]
AL00	0.02	0.00	0.16
AT00	1.30	0.00	1.32
BA00	0.73	0.00	1.02
BE00	3.47	0.00	16.06
BG00	0.04	0.00	0.00
CH00	0.00	0.00	0.00
CY00	0.00	0.00	0.00
CZ00	0.00	0.00	0.00
DE00	56.73	2.44	182.55
DKE1	1.10	0.00	3.58
DKW1	4.50	0.29	22.04
EE00	0.33	0.00	2.24
ES00	11.10	4.83	48.19
FI00	1.43	0.00	9.51
FR00	17.75	0.00	52.02
GR00	0.08	0.00	0.36
GR03	0.04	0.00	0.20
HR00	0.00	0.00	0.00
HU00	5.81	0.00	19.47
IE00	8.19	6.72	21.04
ITCA	0.00	0.00	0.00
ITCN	3.72	0.00	13.04
ITCS	0.58	0.00	0.13
ITN1	0.31	0.00	0.00
ITS1	0.00	0.00	0.00
ITSA	0.08	0.00	0.24
ITSI	0.00	0.00	0.00
LT00	0.58	0.00	3.76
LUG1	0.67	0.03	2.16
LV00	0.00	0.00	0.00
ME00	0.00	0.00	0.00
MK00	0.28	0.00	0.63
MT00	1.60	0.47	7.87
NL00	0.03	0.00	0.00
NOM1	0.00	0.00	0.00
NON1	0.00	0.00	0.00
NOS0	0.00	0.00	0.00

BZ	Without CM – TY 2025		
	Average [GWh]	P50 [GWh]	Average [GWh]
PL00[4]	0.00	0.00	0.00
PT00	0.00	0.00	0.00
RO00	0.61	0.00	1.20
RS00	1.28	0.00	1.98
SE01	0.00	0.00	0.00
SE02	0.00	0.00	0.00
SE03	1.12	0.00	5.12
SE04	0.73	0.00	4.33
SI00	0.12	0.00	0.13
SK00	0.00	0.00	0.00
TR00	0.69	0.00	4.24
UK00	10.48	1.14	46.16
UKNI	0.07	0.00	0.37

Table 8: Country EENS (average) and ENS percentiles for the scenario without CM, for TY 2025

Country	Without CM – TY 2025		
	Average [GWh]	P50 [GWh]	Average [GWh]
DK00	5.61	0.34	23.41
ISEM	8.26	6.80	21.62
IT00	4.69	0.17	13.04
LU00	0.67	0.03	2.16
NO00	0.00	0.00	0.00
SE00	1.85	0.00	9.61

[4] Practically speaking, there is no scenario without CM for Poland for the period up to and including 2026 as CM auctions have been already conducted for this period. Therefore, LOLE / EENS results for Poland in 2025 for the scenario without CM are lowered by the use of DSR contracted for this year.

Table 9: BZ LOLE (average) and LLD percentiles for the scenario without CM, for TY 2027

BZ	Without CM – TY 2027		
	Average [h/year]	P50 [h/year]	P95 [h/year]
AL00	0.5	0.0	2.0
AT00	1.2	0.0	6.0
BA00	0.9	0.0	2.0
BE00	10.4	0.0	51.0
BG00	0.7	0.0	2.0
CH00	0.2	0.0	0.0
CY00	0.0	0.0	0.0
CZ00	0.0	0.0	0.0
DE00	13.7	6.0	63.0
DKE1	11.1	3.0	56.0
DKW1	13.4	4.0	63.0
EE00	9.7	0.0	50.0
ES00	1.9	0.0	8.0
FI00	1.6	0.0	15.0
FR00	8.7	0.0	38.0
GR00	0.1	0.0	0.0
GR03	0.4	0.0	2.0
HR00	0.0	0.0	0.0
HU00	2.3	0.0	6.0
IE00	1.6	0.0	9.0
ITCA	0.0	0.0	0.0
ITCN	9.9	0.0	46.0
ITCS	1.5	0.0	6.0
ITN1	0.5	0.0	3.0
ITS1	0.0	0.0	0.0
ITSA	0.1	0.0	0.0
ITSI	0.0	0.0	0.0
LT00	6.2	0.0	44.0
LUG1	13.7	6.0	63.0
LV00	0.2	0.0	0.0
ME00	0.0	0.0	0.0
MK00	1.1	0.0	5.0
MT00	0.1	0.0	0.0
NL00	0.8	0.0	5.0
NOM1	0.0	0.0	0.0
NON1	0.0	0.0	0.0
NOS0	0.0	0.0	0.0
PL00	0.2	0.0	0.0

BZ	Without CM – TY 2027		
	Average [h/year]	P50 [h/year]	P95 [h/year]
PT00	0.0	0.0	0.0
RO00	0.2	0.0	0.0
RS00	1.2	0.0	4.0
SE01	0.0	0.0	0.0
SE02	0.0	0.0	0.0
SE03	2.5	0.0	18.0
SE04	5.1	0.0	48.0
SI00	0.4	0.0	0.0
SK00	0.0	0.0	0.0
TR00	0.2	0.0	1.0
UK00	4.2	0.0	17.0
UKNI	1.4	0.0	9.0

Table 10: Country LOLE (average) and LLD percentiles for the scenario without CM, for TY 2027

Country	Without CM – TY 2027		
	Average [h/year]	P50 [h/year]	P95 [h/year]
DK00	15.2	5.0	67.0
ISEM	2.4	0.0	12.0
IT00	10.1	1.0	46.0
LU00	13.7	6.0	63.0
NO00	0.0	0.0	0.0
SE00	5.2	0.0	48.0

Table 11: BZ EENS (average) and ENS percentiles for the scenario without CM, for TY 2027

BZ	Without CM – TY 2027		
	Average [GWh]	P50 [GWh]	Average [GWh]
AL00	0.02	0.00	0.07
AT00	0.76	0.00	1.59
BA00	0.16	0.00	0.09
BE00	9.61	0.00	44.05
BG00	0.22	0.00	0.29
CH00	0.08	0.00	0.00
CY00	0.00	0.00	0.00
CZ00	0.00	0.00	0.00
DE00	90.06	10.34	381.65
DKE1	2.30	0.19	13.37
DKW1	8.71	1.41	50.09
EE00	1.75	0.00	12.69
ES00	3.08	0.00	15.79
FI00	0.57	0.00	3.87
FR00	29.80	0.00	119.81
GR00	0.06	0.00	0.00
GR03	0.02	0.00	0.06
HR00	0.00	0.00	0.00
HU00	1.65	0.00	2.60
IE00	0.40	0.00	2.72
ITCA	0.00	0.00	0.00
ITCN	5.11	0.00	20.22
ITCS	1.71	0.00	1.50
ITN1	0.55	0.00	2.19
ITS1	0.00	0.00	0.00
ITSA	0.02	0.00	0.00
ITSI	0.00	0.00	0.00
LT00	1.21	0.00	10.19
LUG1	1.06	0.12	4.51
LV00	0.01	0.00	0.00
ME00	0.00	0.00	0.00
MK00	0.20	0.00	0.32
MT00	0.02	0.00	0.00
NL00	0.48	0.00	2.98
NOM1	0.00	0.00	0.00
NON1	0.00	0.00	0.00
NOS0	0.00	0.00	0.00
PL00	0.15	0.00	0.00
PT00	0.00	0.00	0.00

BZ	Without CM – TY 2027		
	Average [GWh]	P50 [GWh]	Average [GWh]
RO00	0.07	0.00	0.00
RS00	0.53	0.00	0.71
SE01	0.00	0.00	0.00
SE02	0.00	0.00	0.00
SE03	1.55	0.00	11.39
SE04	2.82	0.00	23.74
SI00	0.03	0.00	0.00
SK00	0.00	0.00	0.00
TR00	0.20	0.00	0.09
UK00	10.32	0.00	46.55
UKNI	0.14	0.00	0.87

Table 12: Country EENS (average) and ENS percentiles for the scenario without CM, for TY 2027

Country	Without CM – TY 2027		
	Average [GWh]	P50 [GWh]	Average [GWh]
DK00	11.01	1.85	60.89
ISEM	0.54	0.00	3.47
IT00	7.39	0.02	21.94
LU00	1.06	0.12	4.51
NO00	0.00	0.00	0.00
SE00	4.36	0.00	34.87

Table 13: BZ LOLE (average) and LLD percentiles for the scenario without CM, for TY 2030

BZ	Without CM – TY 2030		
	Average [h/year]	P50 [h/year]	P95 [h/year]
AL00	0.0	0.0	0.0
AT00	0.6	0.0	2.0
BA00	2.8	0.0	7.0
BE00	11.0	4.0	45.0
BG00	1.2	0.0	4.0
CH00	0.8	0.0	4.0
CY00	0.0	0.0	0.0
CZ00	0.5	0.0	2.0
DE00	20.4	7.0	82.0
DKE1	10.9	4.0	52.0
DKW1	2.3	0.0	15.0
EE00	8.0	0.0	43.0
ES00	1.5	0.0	7.0
FI00	2.1	0.0	18.0
FR00	10.2	0.0	42.0
GR00	0.0	0.0	0.0
GR03	0.1	0.0	0.0
HR00	0.0	0.0	0.0
HU00	3.9	0.0	16.0
IE00	2.4	0.0	9.0
ITCA	0.0	0.0	0.0
ITCN	8.7	0.0	35.0
ITCS	2.2	0.0	7.1
ITN1	0.5	0.0	4.0
ITS1	0.0	0.0	0.0
ITSA	0.4	0.0	2.0
ITSI	0.0	0.0	0.0
LT00	6.0	0.0	39.0
LUG1	20.4	7.0	82.0
LV00	0.1	0.0	0.0
ME00	0.0	0.0	0.0
MK00	1.1	0.0	6.0
MT00	0.0	0.0	0.0
NL00	4.5	1.0	20.0
NOM1	0.0	0.0	0.0
NON1	0.0	0.0	0.0
NOS0	0.0	0.0	0.0
PL00	2.0	0.0	15.0

BZ	Without CM – TY 2030		
	Average [h/year]	P50 [h/year]	P95 [h/year]
PT00	0.0	0.0	0.0
RO00	0.1	0.0	0.0
RS00	2.8	0.0	7.0
SE01	0.0	0.0	0.0
SE02	0.0	0.0	0.0
SE03	1.2	0.0	11.0
SE04	5.5	0.0	38.0
SI00	1.8	0.0	1.0
SK00	0.0	0.0	0.0
TR00	0.7	0.0	4.0
UK00	2.7	0.0	10.0
UKNI	1.6	1.0	8.0

Table 14: Country LOLE (average) and LLD percentiles for the scenario without CM, for TY 2030

Country	Without CM – TY 2030		
	Average [h/year]	P50 [h/year]	P95 [h/year]
DK00	11.2	4.0	53.0
ISEM	3.1	1.0	12.0
IT00	9.0	0.0	35.0
LU00	20.4	7.0	82.0
NO00	0.0	0.0	0.0
SE00	5.5	0.0	38.0

Table 15: BZ EENS (average) and ENS percentiles for the scenario without CM, for TY 2030

BZ	Without CM – TY 2030		
	Average [GWh]	P50 [GWh]	Average [GWh]
AL00	0.00	0.00	0.00
AT00	0.49	0.00	0.57
BA00	0.77	0.00	1.20
BE00	11.54	1.35	55.47
BG00	0.36	0.00	0.78
CH00	0.85	0.00	2.82
CY00	0.00	0.00	0.00
CZ00	0.21	0.00	0.25
DE00	172.19	54.50	745.13
DKE1	2.45	0.30	13.15
DKW1	0.85	0.00	7.28
EE00	1.35	0.00	8.33
ES00	2.30	0.00	11.20
FI00	1.00	0.00	8.87
FR00	41.49	0.00	186.26
GR00	0.00	0.00	0.00
GR03	0.00	0.00	0.00
HR00	0.00	0.00	0.00
HU00	2.27	0.00	6.55
IE00	0.57	0.00	2.86
ITCA	0.00	0.00	0.00
ITCN	3.72	0.00	12.42
ITCS	2.40	0.00	3.20
ITN1	0.73	0.00	2.67
ITS1	0.00	0.00	0.00
ITSA	0.07	0.00	0.11
ITSI	0.00	0.00	0.00
LT00	1.46	0.00	11.00
LUG1	2.00	0.63	8.63
LV00	0.00	0.00	0.00
ME00	0.00	0.00	0.00
MK00	0.10	0.00	0.21
MT00	0.00	0.00	0.00
NL00	4.82	0.73	23.07
NOM1	0.00	0.00	0.00
NON1	0.00	0.00	0.00
NOS0	0.00	0.00	0.00
PL00	1.48	0.00	11.77
PT00	0.00	0.00	0.00

BZ	Without CM – TY 2030		
	Average [GWh]	P50 [GWh]	Average [GWh]
RO00	0.04	0.00	0.00
RS00	1.96	0.00	3.67
SE01	0.00	0.00	0.00
SE02	0.00	0.00	0.00
SE03	1.03	0.00	3.84
SE04	3.12	0.00	26.12
SI00	0.44	0.00	0.07
SK00	0.00	0.00	0.00
TR00	0.91	0.00	4.40
UK00	7.48	0.00	34.29
UKNI	0.23	0.01	1.53
Total	273.22	\	\

Table 16: Country EENS (average) and ENS percentiles for the scenario without CM, for TY 2030

Country	Without CM – TY 2030		
	Average [GWh]	P50 [GWh]	Average [GWh]
DK00	3.30	0.38	20.10
ISEM	0.80	0.06	3.92
IT00	6.93	0.00	16.07
LU00	2.00	0.63	8.63
NO00	0.00	0.00	0.00
SE00	4.15	0.00	28.03

3.2.2 Scarcity events description

This section aims to describe the likelihood of scarcity events for given CYs and TY months as well as the likelihood of simultaneous scarcity events but does not aim to draw conclusions on the drivers/sources causing scarcity events.

Scarcity events are defined as those hours of the simulation in which, for any BZ, the ENS is higher than 0. It occurs when a BZ is unable to meet its own demand after maximising its generation and imports. The challenge is whether conditions can cause stress on the adequacy of the system e.g. increased demand due to colder-than-average weather.

Figure 6 illustrates the ENS per TY month and CY averaged across all forced outage (FO) samples in the ERAA explicit region. It shows that CY 1985 is by far the one with the highest impact, followed by 1997 and 1986. It is also noticeable that the months with the higher impact are winter months. The analysis shows that the impact of scarcity events on ENS is more pronounced for more distant TYs and always in the same months for a given CY. Although the effects of large-scale weather conditions affecting a significant number of regions are more visible on the figure, it should be noted that individual BZs may be impacted by smaller scale weather conditions.

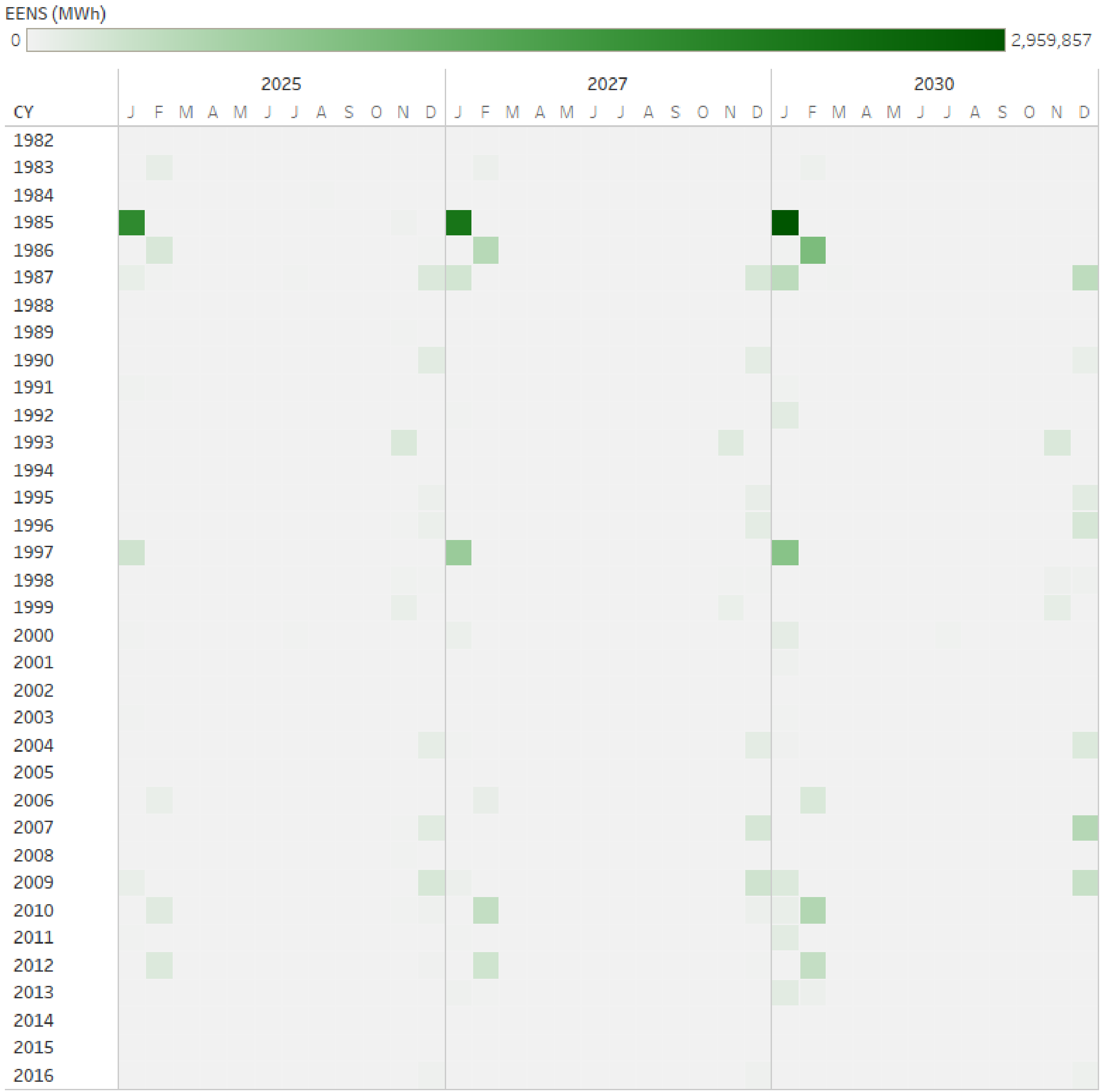


Figure 6: ENS per climatic year and TY month – scenario without CM

Figure 8 focuses on the correlations of scarcity events between several European regions (illustrated in Figure 7) excluding Ukraine and Türkiye[5]. More specifically, it illustrates the frequency or probability of a region (target region) experiencing a scarcity event simultaneously to a reference region.

[5] The aggregation was performed using as guidance the ACER Decision 04-2021 on the Determination of Capacity Calculation Regions.

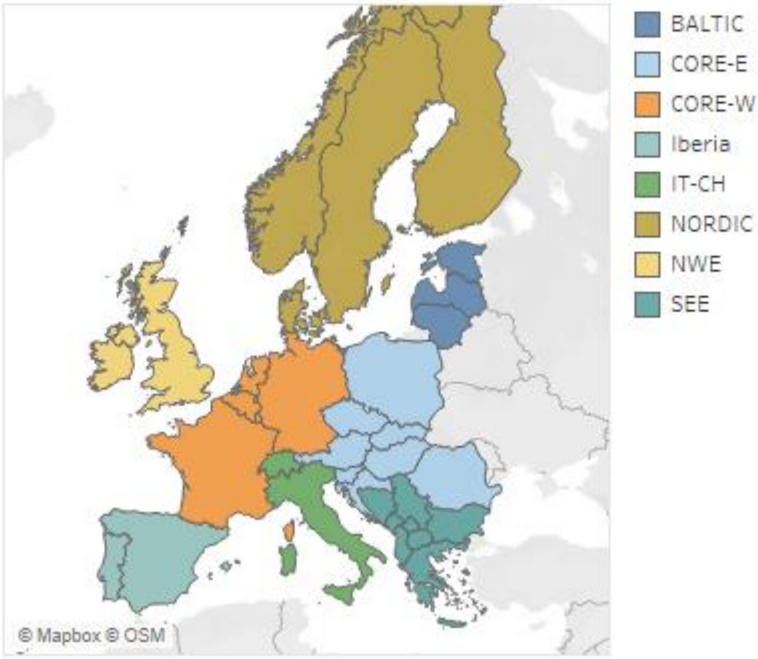


Figure 7: Geographical scope for simultaneous scarcity analysis

The table is interpreted by selecting a reference region in the rows (region X) and then a target region in the columns (region Y). The value given expresses the probability of target region Y experiencing a scarcity event given a scarcity event in reference region X. In mathematical terms, see Eq. 1:

$$\text{Simultaneous scarcicy probability} := \mathrm{P}\,(\mathrm{Y} = Y_s \mid \mathrm{X} = X_s) = \frac{P(Y=Y_s,\ X=X_s)}{P(X=X_s)}, \quad (1)$$

where Y and X represent the regions described below (X being the reference region), while Y_s and X_s represent the scarcity situation in Y and X respectively.

Simultaneous scarcity ratio

0% — 100%

TY 2025

	Baltic	Core-E	Core-W	Iberia	It-Ch	Nordic	NWE	SEE
BALTIC		34%	48%	16%	39%	79%	51%	24%
CORE-E	80%		96%	34%	87%	94%	73%	66%
CORE-W	69%	60%		31%	70%	84%	61%	40%
IBERIA (SWE)	46%	41%	62%		49%	62%	83%	30%
IT-CH	52%	51%	65%	23%		64%	54%	37%
NORDIC	62%	31%	45%	17%	37%		45%	21%
NWE	16%	10%	13%	9%	13%	18%		8%
SEE	73%	86%	83%	32%	82%	81%	80%	

TY 2027

	Baltic	Core-E	Core-W	Iberia	It-Ch	Nordic	NWE	SEE
BALTIC		11%	29%	6%	23%	37%	16%	7%
CORE-E	95%		100%	22%	97%	100%	67%	59%
CORE-W	70%	28%		14%	67%	82%	46%	18%
IBERIA (SWE)	70%	29%	66%		52%	61%	59%	17%
IT-CH	67%	33%	81%	14%		77%	46%	21%
NORDIC	79%	25%	71%	12%	56%		38%	15%
NWE	70%	34%	83%	23%	69%	79%		23%
SEE	76%	70%	73%	15%	75%	72%	53%	

TY 2030

	Baltic	Core-E	Core-W	Iberia	It-Ch	Nordic	NWE	SEE
BALTIC		27%	51%	5%	33%	67%	23%	18%
CORE-E	78%		100%	11%	84%	90%	50%	59%
CORE-W	55%	37%		8%	60%	72%	41%	25%
IBERIA (SWE)	57%	39%	84%		66%	61%	73%	38%
IT-CH	46%	41%	79%	9%		64%	42%	30%
NORDIC	72%	34%	72%	6%	49%		31%	23%
NWE	33%	25%	54%	10%	43%	41%		22%
SEE	71%	81%	92%	14%	85%	83%	61%	

Figure 8: Simultaneous scarcity tables for all TYs (reference regions in X-axis)

In general terms, the results show a high scarcity correlation between the regions under study. More specifically, CORE-W and Nordic tend to suffer scarcity when any of the other regions are in scarcity, whereas Iberia and SEE regions show the opposite behaviour. In addition, when CORE-E and SEE regions are in scarcity, most other regions are likely to experience scarcity.

3.2.3 Sources of scarcity

The purpose of this section is to identify and gain insight on the main drivers/sources of scarcity. Equation 2 details the "balance constraint" expressing the ENS during a scarcity event is described in mathematical terms in:

$$ENS_{h,z} = Load_{h,z} - Generation_{h,z} - Imports_{h,z} + Exports_{\ h,z} \ (2)$$

Where:h stands for hours and z for bidding zone.

This equation is valid for any MC run (for any TY, CY and FO pattern). As such the Load, Generation and the balance of Imports and Exports during scarcity can be drivers of scarcity.

As the values of Load, Generation and the balance of Imports and Exports can vary drastically from one bidding zone to another, calculated ratios are reported in the figures below to allow for comparison across bidding zones. The ratios are described below:

- Exogenous Load[6] percentile during scarcity

The exogenous load during scarcity is reported hourly, for each bidding zone and TY. To make values from different bidding zones comparable, values are reported as the percentile rank (e.g., 98th percentile) with respect to a single distribution of all hourly load values for all CY. These percentile ranks of hourly load during scarcity are computed repeatedly for each TY and bidding zone, each time comparing with the corresponding distribution of hourly values for all CY.

The percentile is used in order to assess whether scarcity events occur mostly during events of unusually high load (high load percentile).

- Generation is reported as Generation availability:

$$Generation\ availability_{hs,z} = \frac{Generation_{hs,z}}{Installed\ Capacity_z} \ (3)\ ,$$

where hs stands for hours with scarcity and z for bidding zones.

- The balance of Imports and Exports as the Share of imports/exports relative to load:

$$Share\ of\ imports/exports\ relative\ to\ load_{hs,z} = \frac{Net\ Position_{hs,z}}{Load_{hs,z}} \ (4)\ ,$$

[6] Exogenous Load refers to the load as provided by TSOs during the data collection process.

where, again, hs represents each hour with scarcity and z represents each bidding zone. For $Net\ Position_{hs,z}$, a positive value means an exporting position, while a negative means an importing position.
The analysis to identify the sources of scarcity was performed for the 6 bidding zones with the highest LOLE. In the figures below, Exogenous Load percentile during scarcity is reported in the shape of a histogram. The X-axis is defined as the "Contribution to LOLE" of each Exogenous load percentile. The contribution to LOLE is simply the count of scarcity hours in each bin (represented by the histogram), but divided by number of Monte Carlo realisations. In this way, the total LOLE value shown above can be analysed as being composed of the LOLE contribution per exogenous load percentile. Specifically in the figure shown, each bin in the graph accounts for all scarcity hours within two percentiles of exogenous load. For example, the top bar shows all ENS occurrences in which Exogenous Load for that hour is in between the 98th and the 100th percentile, divided by the amount of MC realisations.

For both *Generation availability* and *Share of imports/exports relative to load*, the boxplots in the figures are built per bidding zone z, based on the distribution of data points for all hours in scarcity hs of each bidding zone. In the figures, *Share of imports/exports relative to load* is referred to as *Net Position relative to load*.

3.2.3.1 TY 2025

Figure 9 shows that DE00 and DKE1 adequacy risks are observed only for hours with unusual high load of the given bidding zones.
However, scarcity in non-continental bidding zones like IE00, MT00 occurs during hours without unusual high load. ITCN also show relevant scarcity risks, but they are not only linked to high peak load events.

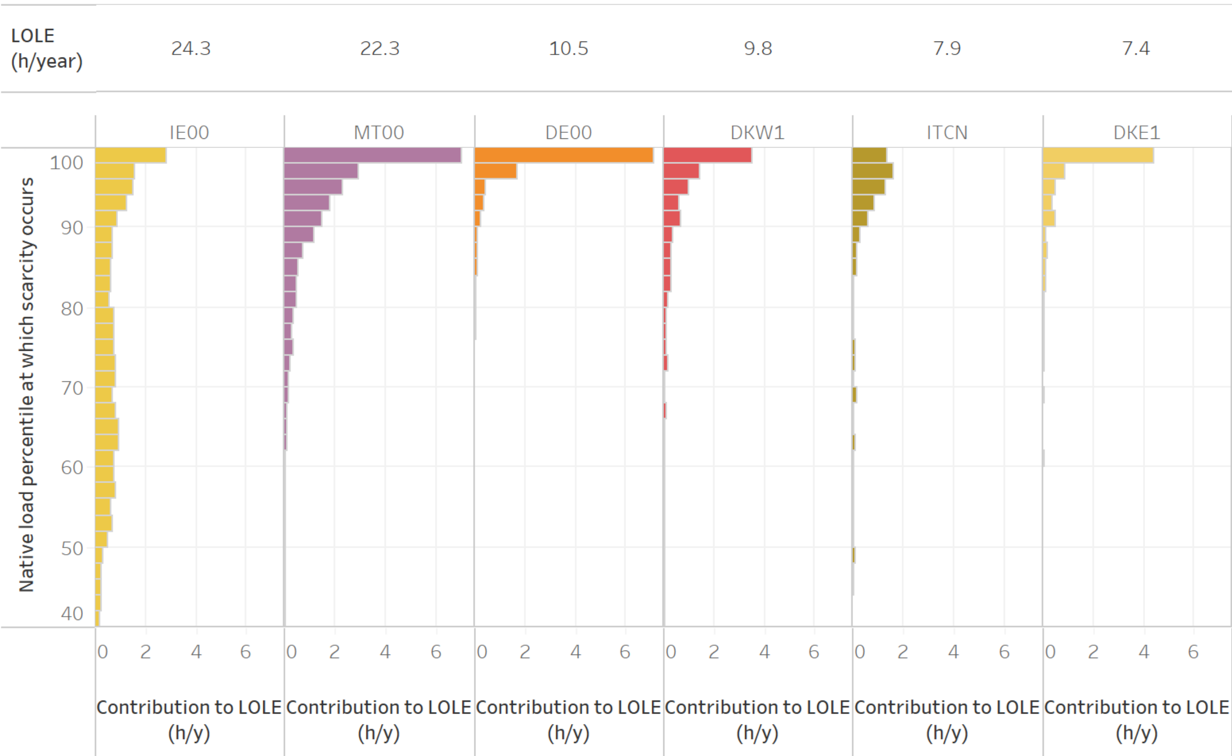


Figure 9: Exogenous Load at which scarcity occurs. TY 2025.

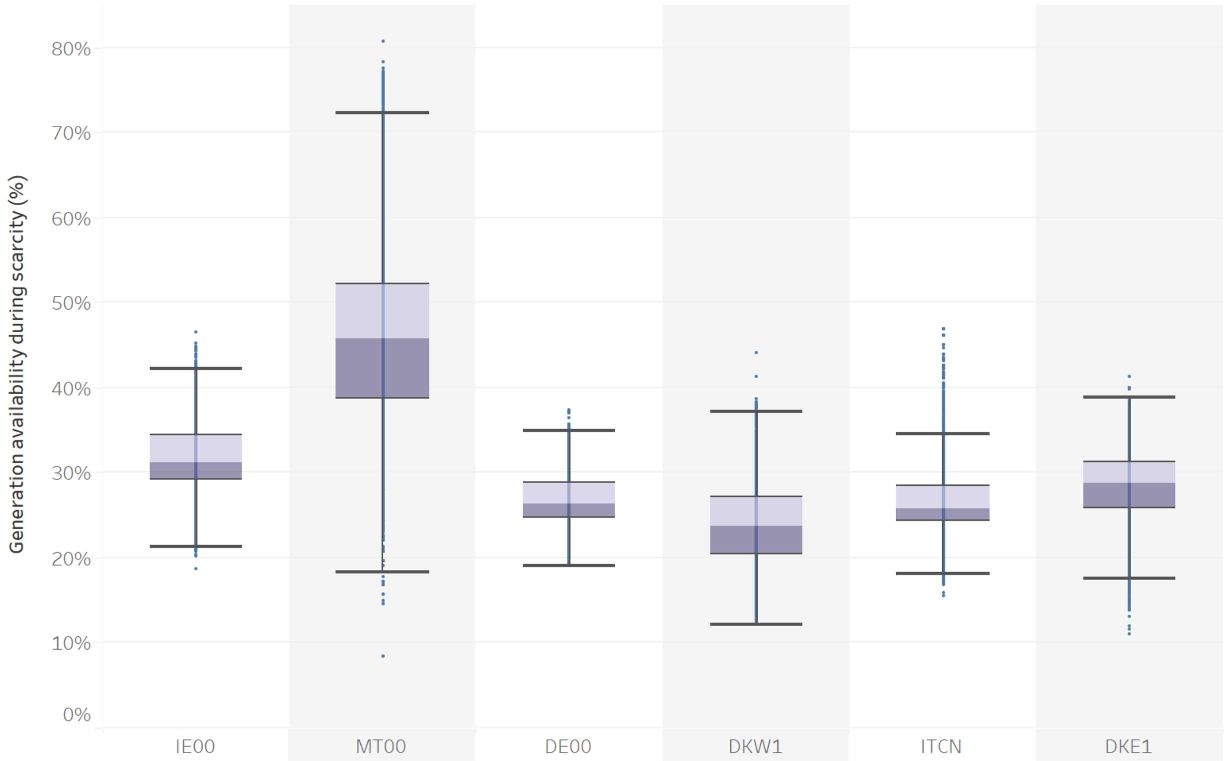


Figure 10: Generation availability during scarcity. TY 2025.

Regarding Generation availability, for TY 2025, the continental bidding zones studied (DE00, DKW1, ITCN and DKE1) show ranges of values which do not vary significantly from each other. Regarding the other two bidding zones; while IE00 tends to have a generation availability in between 20% and 42%, MT00 has a larger range of generation availabilities during scarcity.

According to the data shown in Figure 11, DE00 is less reliant on imports to meet its own demand during periods of scarcity, when compared to other bidding zones in continental Europe. Particularly MT00, concentrates most occurrences of ENS in a Net Position equal to 0 (unavailability to import). This is shown in the graph below with a solid line in the 0%.

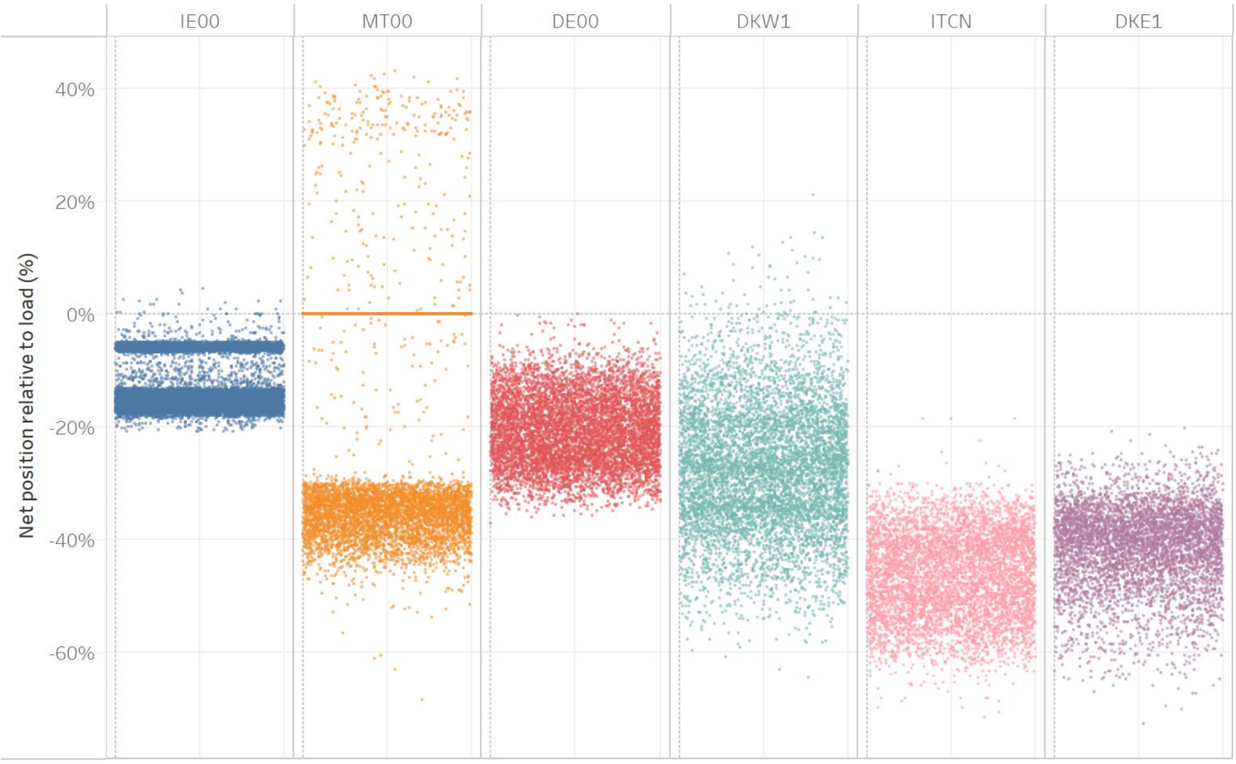


Figure 11: Net Position during scarcity, relative to load. TY 2025.

In principle, implementation of Local Matching ensures that a bidding zone is not exporting during scarcity hours. However, the implementation in ERAA 2022 still allowed for a small amount of scarcity hours with exporting positions in some bidding zones. Note that this refers to less than 4% of the scarcity hours of each TY.

3.2.3.2 TY 2027

In TY2027, MT00 and IE00 have a sharp decrease in LOLE, while most other bidding zones show larger risks of inadequacy than in 2025.

In terms of load and generation availability during scarcity, the behaviour in DKE1, DKW1, ITCN and DE00 is quite similar as the one described above for TY 2025, except for a lower generation availability overall.

As shown in Figure 12, most scarcity events in BE00 are linked to hours with unusual high load. Regarding Generation availability, for TY 2027, BE00 show values significantly higher than the other bidding zones.

According to the data shown in Figure 14, EE00 is more reliant on imports to meet its own demand during periods of scarcity, while BE00 and DE00 rely less on imports during scarcity situations.

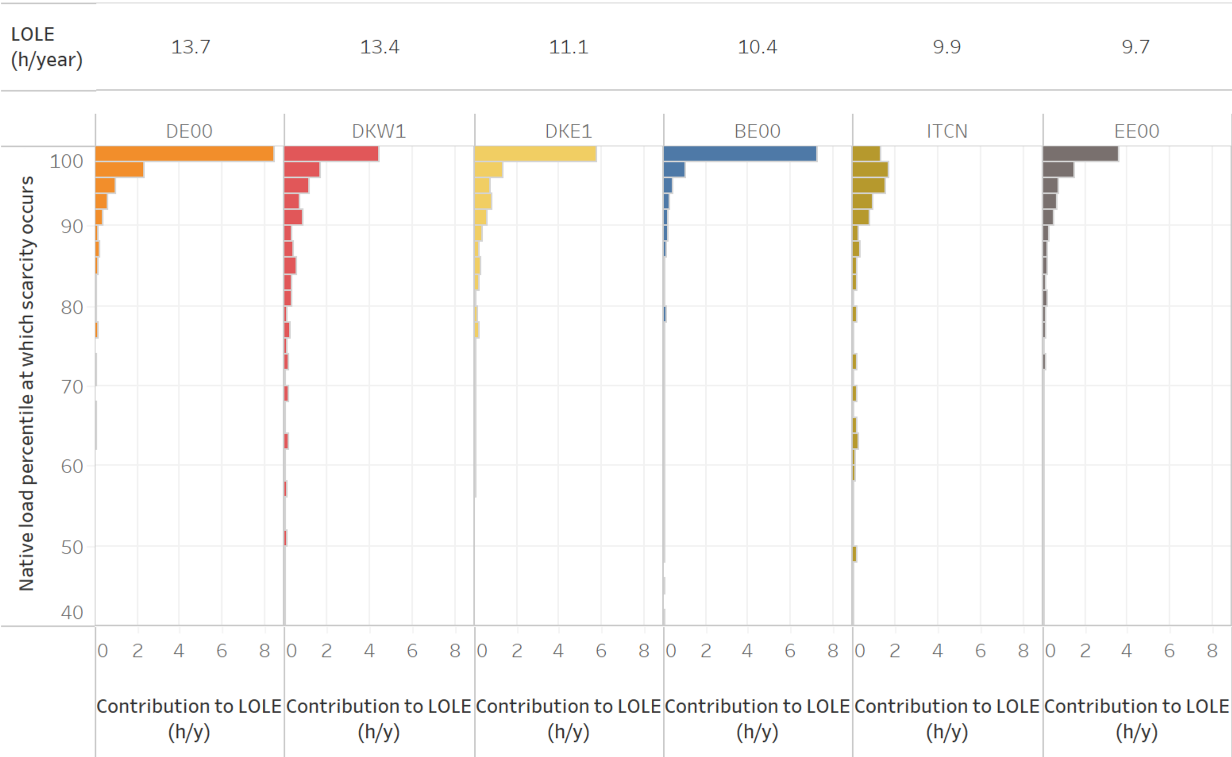


Figure 12: Exogenous Load at which scarcity occurs. TY 2027.

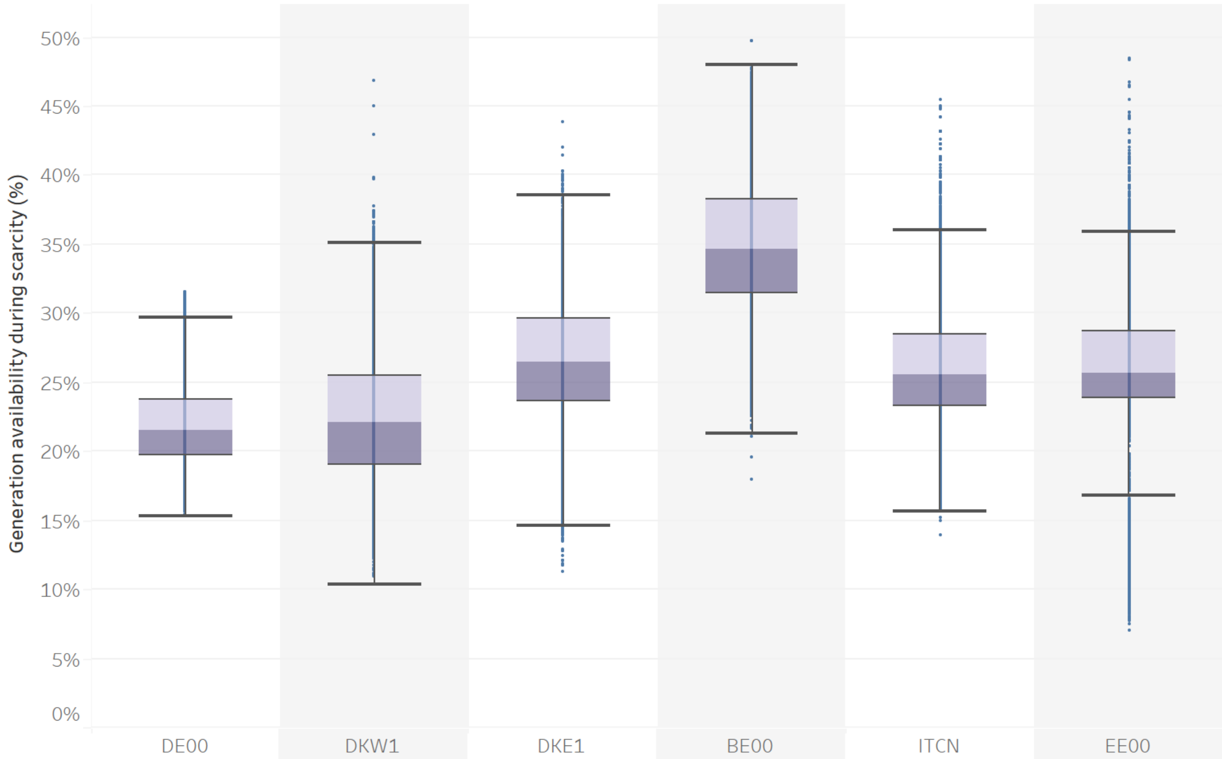


Figure 13: Generation availability during scarcity. TY 2027.

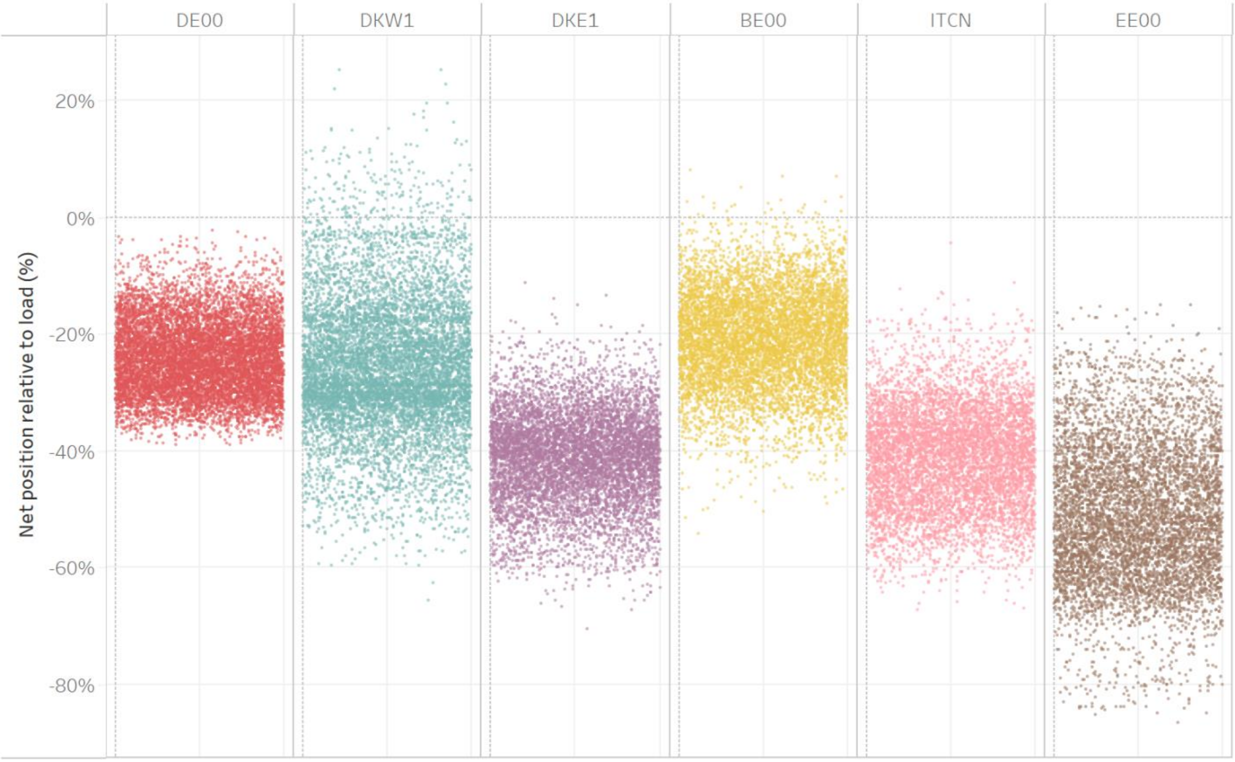


Figure 14: Net Position during scarcity, relative to load. TY 2027.

3.2.3.3 TY 2030

In TY 2030, scarcity risks increase for FR00, BE00 and specially for DE00. In terms of sources of scarcity, BE00 and DE00 continue showing similar results are the ones described for TY2027.

Regarding Generation availability, for TY 2025, FR00 show values significantly higher than the other continental bidding zones. FR00 is also less reliant on imports from other bidding zones to meet its own demand during periods of scarcity, when compared to other bidding zones in continental Europe. In terms of load (Figure 15), FR00 adequacy risks are observed only for hours with unusual high load.

In other bidding zones like ITCN, DKE1 and EE00, scarcity risks decrease moderately when compared to TY2027. The analysis of sources of scarcity for these bidding zones in TY2030 is similar to the one performed for TY2027, with a few changes, like a slight increase in the generation availability during scarcity for these three bidding zones in TY2030.

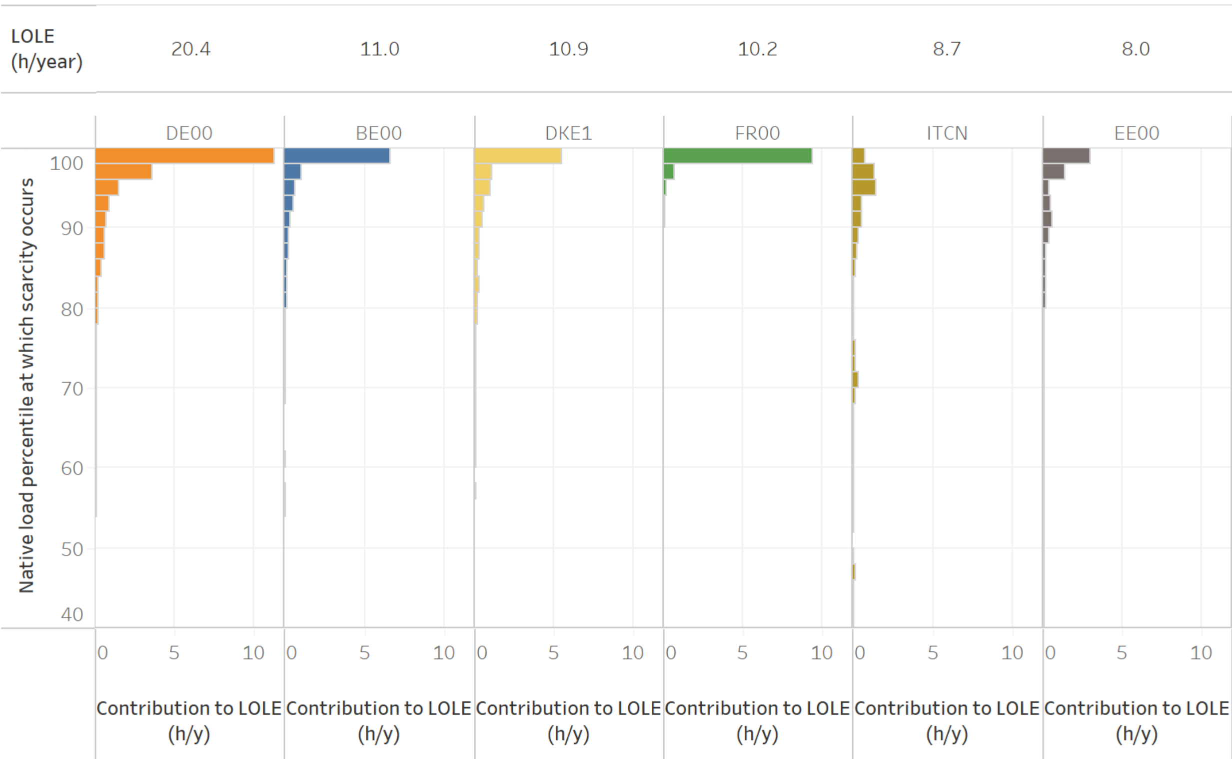


Figure 15: Exogenous Load at which scarcity occurs. TY 2030.

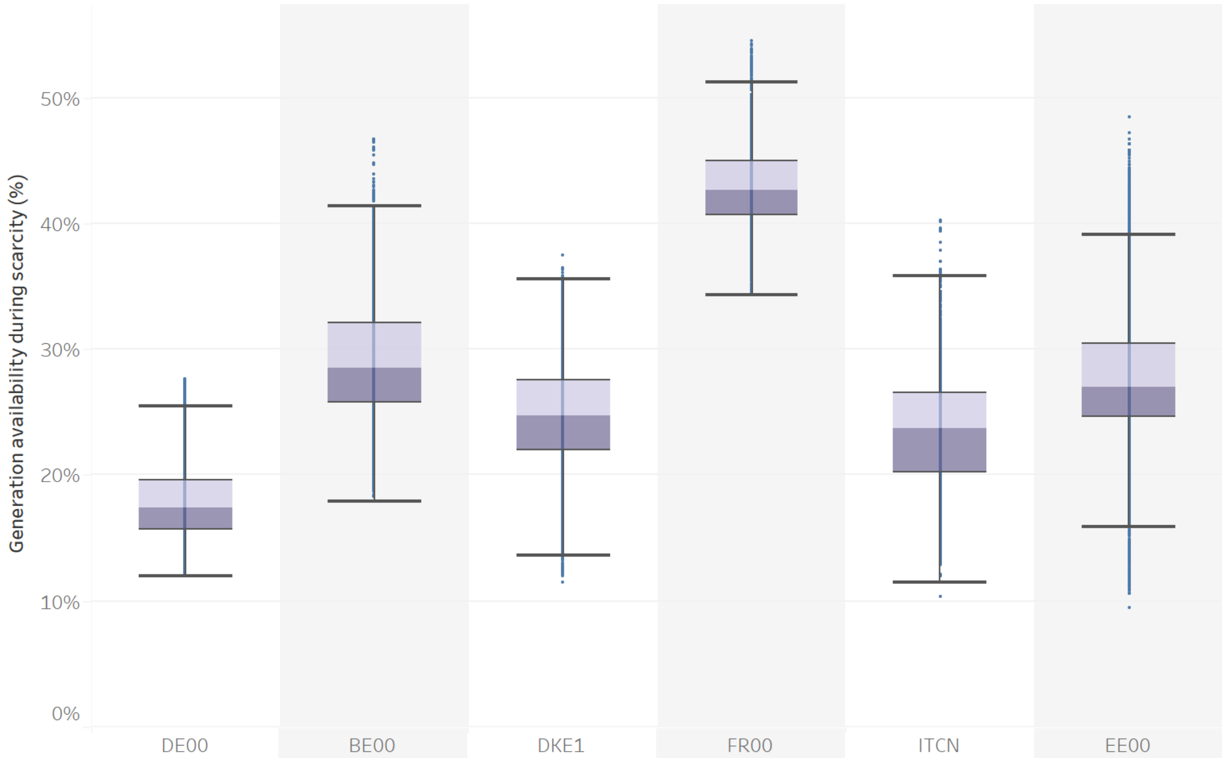


Figure 16: Generation availability during scarcity. TY 2030.

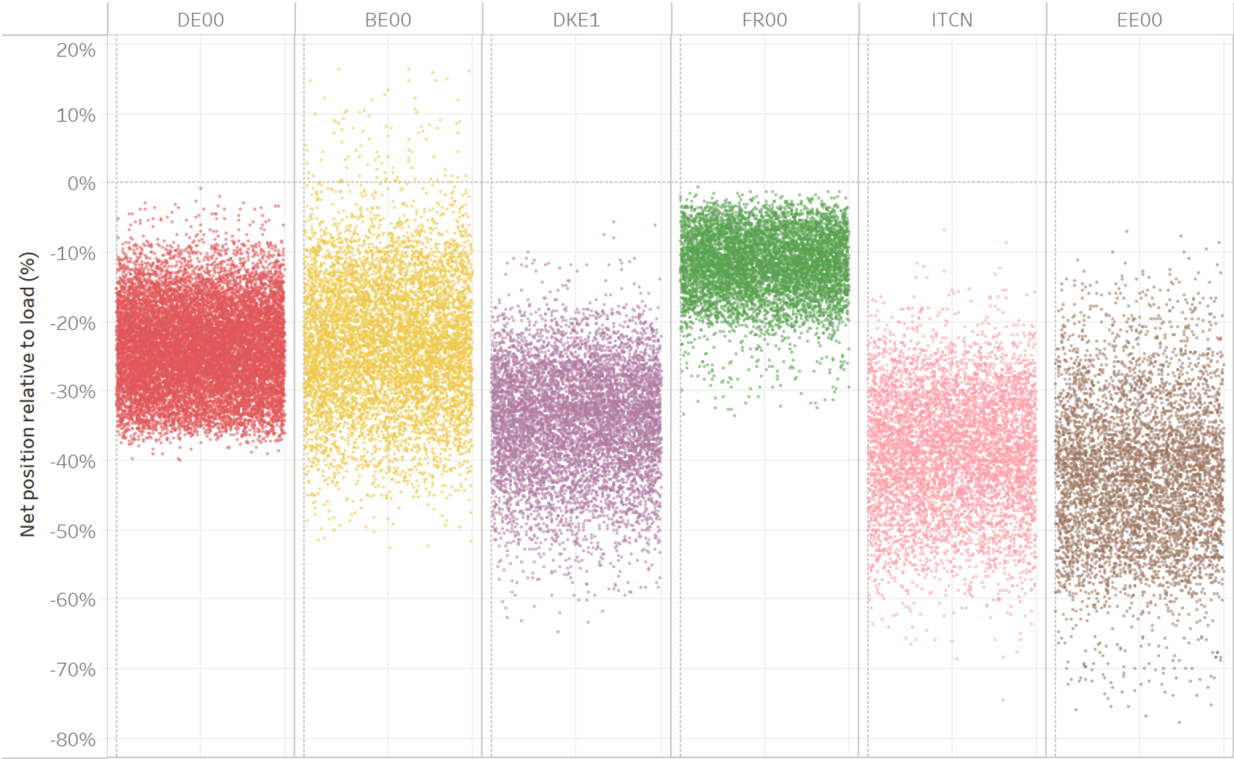
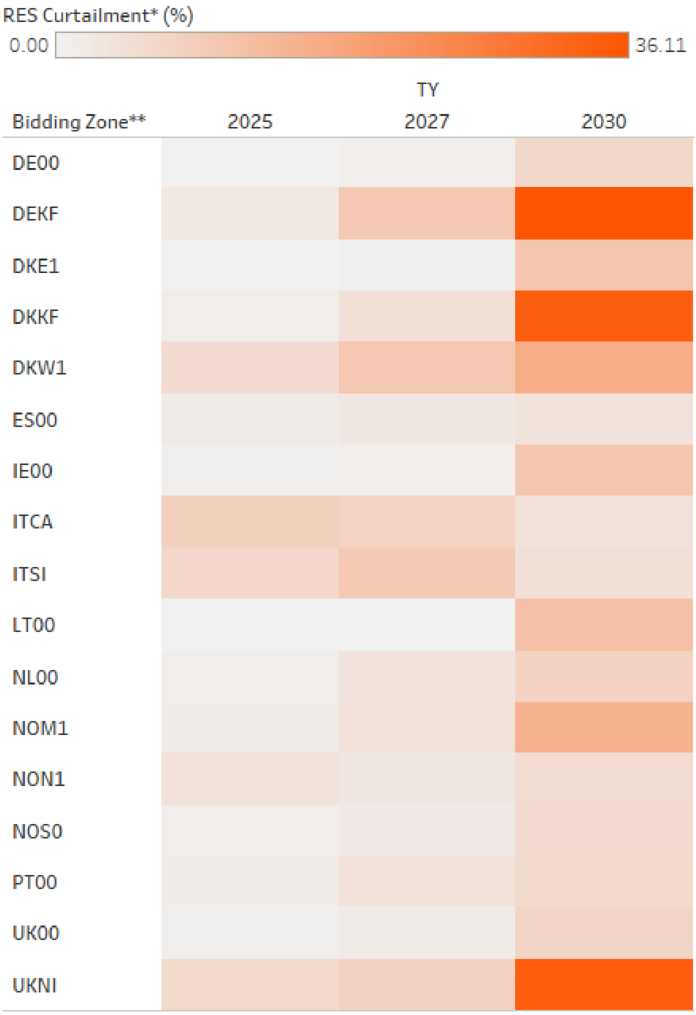


Figure 17: Net Position during scarcity, relative to load. TY 2030.

3.2.4 RES curtailment

The expected increase in RES installed capacities, such as wind and solar power, poses new challenges in the operation of power systems due to its non-dispatchable nature. The potential simultaneity of periods with low costumer load and high RES production may lead to the curtailment of RES production.

Figure 9 depicts the expected RES curtailment ratio for some BZs for each TY averaged across CYs and FO patterns. RES curtailment increases for TYs further in the future as RES installed capacity increases. In some BZs the RES curtailment level reaches high values of 36% for TY 2030. The curtailment ratio averaged across the ERAA explicit region is lower, around 4.5%.



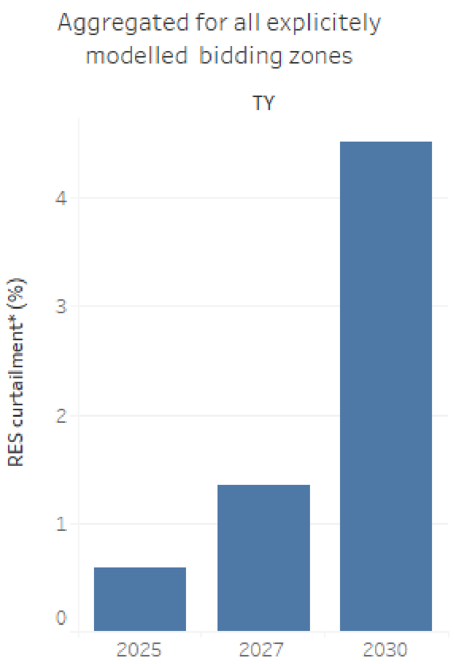


Figure 18: RES Curtailment (%) by TY

3.2.5 Results convergence

To be robust, the MC simulation results must have converged, meaning that the impact of additional MC realisation results on the existing results should be small or negligible (see Annex 2, Section 11.8). It can then be said that the model has converged. This is the behaviour observed in the results for the scenario without CM, once 700 MC realisations of results have been reached, as shown in Figure 19.

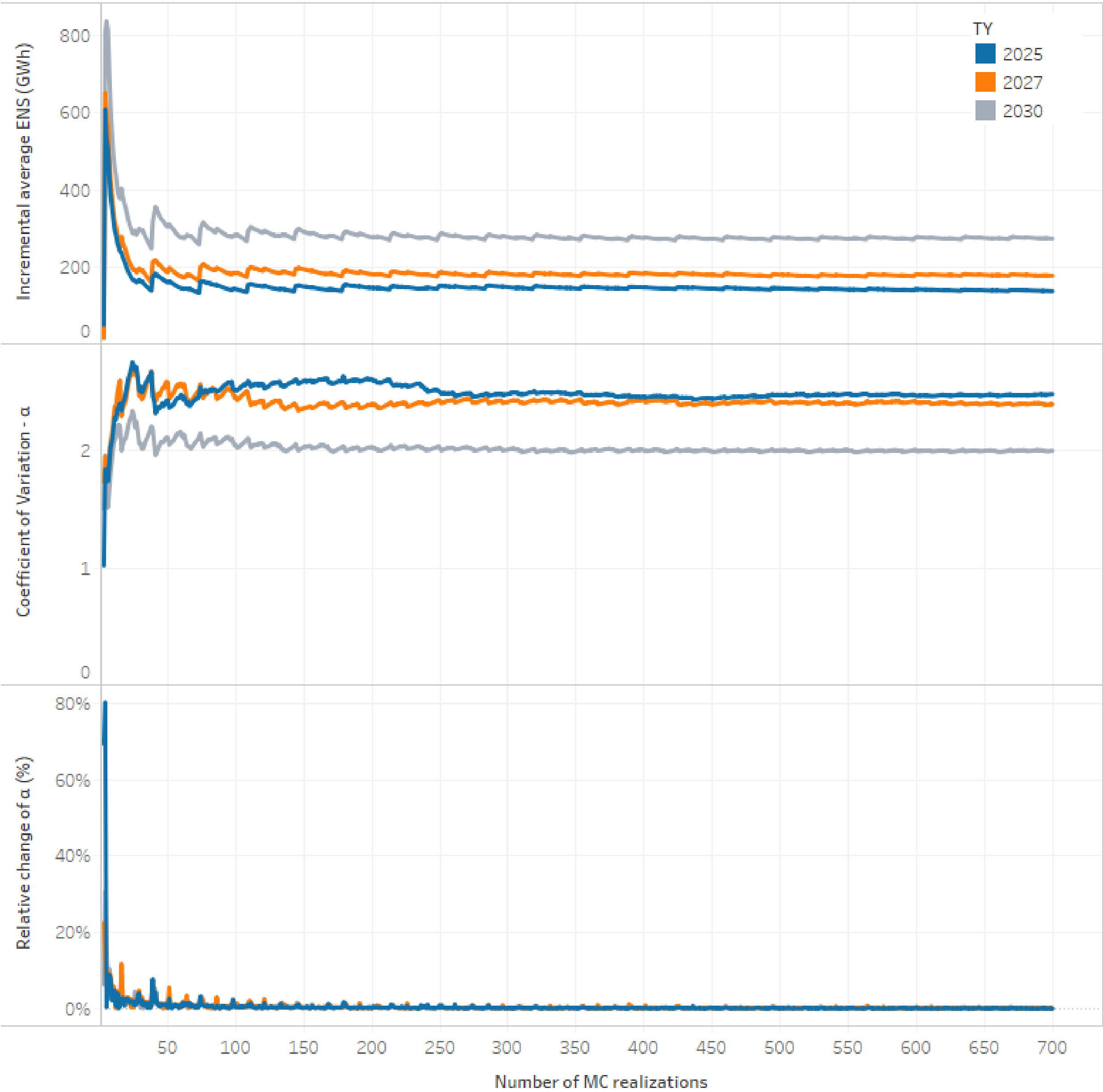


Figure 19: Incremental average ENS, Coefficient of variation α and relative change of α evolution