I. ADEQUACY PATCH

The simulations performed for adequacy studies consider an economic dispatch model which aims to minimise the total systems costs or equivalently maximise the total welfare of the system. In relation to the possible occurrence of Energy Non-Served (ENS), the 'ENS' penalty term = VoLL * ENS, is part of the total system cost. ENS is thus priced at the Value of Lost Load 'VoLL' set in the model (which in the simulations is equal to the Day Ahead Price Cap). In hours in which ENS might occur within the modelled perimeter, the economic dispatch model tries to find solution with the lowest global ENS. However, the situation leading to the minimum global ENS, might in turn lead to a 'non-fair' distribution of ENS among countries in structural shortage, i.e. countries needing imports to ensure its adequacy. A mitigation measure has been implemented in the electricity market to prevent these situations from occurring. The principles of this mitigation measure are presented in this appendix.

I.1. IMPLEMENTATION IN EUPHEMIA

Within the EUPHEMIA algorithm (PCR Market Coupling Algorithm [NEM-1]), a mitigation measure has been implemented to prevent price-taking orders (orders submitted at the price bounds set in the market coupling framework) to be curtailed because of 'flow factor competition'.

The solution implemented in EUPHEMIA within flow-based market coupling (FBMC) follows the curtailment sharing principles that already existed under ATC/NTC. The objective is to equalise the ratio of curtailment (~Energy Non Served (ENS)/Total volume of price-taking orders) between bidding zones as much as possible.

I.2. FLOW FACTOR COMPETITION

If two possible market transactions generate the same welfare, the one having the lowest impact on the scarce transmission capacity will be selected first. It also means that, in order to optimise the use of the grid and to maximise the market welfare, some 'sell' (/buy) bids with lower (/higher) prices than other 'sell' (/buy) bids might not be selected within the flow-based allocation. This is a well-known and intrinsic property of flow-based referred to as 'flow factor competition'.

I.3. FLOW FACTOR COMPETITION AND PRICE TAKING ORDERS

Under normal FBMC circumstances, 'flow factor competition' is accepted as it leads to maximal overall welfare. However for the special case where the situation is exceptionally stressed e.g. due to scarcity in one particular zone, 'flow factor competition' could lead to a situation where order curtailment takes place non-intuitively. This could mean e.g. that some buyers which are ready to pay any price to import energy would be rejected while lower buy bids in other bidding areas are selected instead, due to 'flow factor competition'. These 'pay-any-price' orders are also referred to as 'price-taking orders', as mentioned above, and are valued at the market price cap in the market coupling framework. This would lead to the situation where one bidding area is curtailed while the clearing prices in the other bidding areas are lower or equal to the market price cap. This is the situation that the adequacy patch seeks to mitigate by 'by-passing' flow factor competition in such cases and ensuring maximal imports for zones experiencing curtailment.

I.4. CURTAILMENT SHARING

The situation becomes more complex when two or more markets are simultaneously in curtailment i.e. facing a scarcity situation. For these situations, the mechanism put in place aims to 'fairly' distribute the curtailments across the involved markets by equalizing the curtailed price-taking orders (~ENS) to total price-taking orders ratio between the curtailed zones. The curtailment sharing is implemented by adding a large penalty term into the primal problem plus solving a sub-optimisation problem for the minimisation and sharing of curtailment, where all network constraints are enforced, but only the acceptance of the price taking volume is considered in the objective function. The curtailment ratios weighted by the volumes of price taking orders are therefore minimised (see EUPHEMIA public description for details [NEM-1]).

I.5. IMPLEMENTATION IN ANTARES

The results of the next AdeqFlex'25 study take into account the rules for curtailment minimisation and sharing (aka 'adequacy patch') as defined in EUPHEMIA by applying them directly within the optimisation performed by the Antares Simulator.

The application of these rules directly in the optimisation problem was already considered in the previous study AdeqFlex'23 [ELI-0]. Previously curtailment minimisation and sharing were considered via a post-processing step after the Antares simulation. Now, thanks to an evolution of the Antares Simulator, these rules are integrated directly in the optimisation.

In the simulations performed, the so-called 'curtailed volumes' are equal to the reported Energy Non-Served (ENS), considering the 'adequacy patch' rules. Furthermore, the corresponding 'net positions' reported in the results, (of Belgium, neighboring countries or any country considered in the simulation) are the ones considering the 'adequacy patch' rules.

Since the consideration of the 'adequacy patch' rules in the simulations is now an integral part of the Antares optimisation, these rules are applied internally in the Antares Simulator at every hour in which ENS takes place within the simulation perimeter.

BOX I-1 — ADEQUACY PATCH DIDACTIC EXAMPLE

In order to illustrate the functioning of the adequacy patch rules as described in this appendix, a simple example with 3 zones is shown below:

- **Zone A:** exporting zone with sufficient margin much larger than its load and the available cross-border capacity towards other zones;
- **Zone B:** 1000 MW of Price Taking Orders (PTO) and with no supply;
- **Zone C:** 1000 MW of Price Taking Orders (PTO) and with no supply;

The physical interconnection is defined by one Flow-based constraint as follows:

$-PTDF_{z2z\ A\text{–}C} * NP_C - PTDF_{z2z\ A\text{–}B} * NP_B \leq RAM$

with $PTDF_{z2z\ A\text{–}C}$ being the zone-to-zone PTDF of zone C (with respect to A) = 0.15;

with $PTDF_{z2z\ A\text{–}B}$ being the zone-to-zone PTDF of zone B (with respect to A) = 0.1;

with $NP_{C,B}$ being the Net Position (Exports [+]/Imports [-]) of zone C and B;

with RAM = 100MW being the Remaining Available Margin of the Critical Network Element and Contingency (CNEC).

There are 4 cases possible:

- **Case 1:** All exports from A go to zone B since $PTDF_{z2z\ A\text{–}B} < PTDF_{z2z\ A\text{–}C}$ and thus zone B has a better 'flow factor' than zone C. Since $PTDF_{z2z\ A\text{–}B}$ = 0.1, B can import power to match all its PTO of 1000MW while respecting the flow-based constraint, provided that C does not receive any imports. **Curtailment (ENS) for B is 0 while for C is thus 1000MW.**
- **Case 2:** From a 'market price' perspective, the PTOs of B and C are both price taking orders valued at the price cap of the market. If all imports are directed towards zone C, C can only receive 667MW of imports while respecting the flow-based constraint, provided that zone B does not receive any imports. **Curtailment (ENS) for B is 1000MW, while for C it is 1000 – 667 MW (= 333 MW).**
- **Case 3:** The adequacy patch rules aim to equalise 'curtailment' ratios when sharing imports between B and C while respecting the flow-based constraints. Full equalisation of ratios would be possible e.g. if $PTDF_{z2z\ A\text{–}B} = PTDF_{z2z\ A\text{–}C}$ = 0.15. The 'full equalisation' solution would then be: imports for C and B amount to 333 MW and **ENS for C and B amount to 667MW**.
- **Case 4:** The adequacy patch rules aim to equalise 'curtailment' ratios when sharing imports between B and C while respecting the flow-based constraints. Since the actual flow-based constraint is based on $PTDF_{z2z\ A\text{–}B}$ (=0.1) < $PTDF_{z2z\ A\text{–}C}$ (=0.15), full equalisation of ratios is not possible and the maximum possible equalisation is obtained by the following solution: Import for C = 308 MW, Import for B = 538 MW (ENS for C = 692MW and ENS for B = 462 MW). **This is the solution found by Antares, since the adequacy patch rules are now an integral part of the Antares optimisation.**

FIGURE I-1 — SIMPLE EXAMPLE TO UNDERSTAND THE ADEQUACY PATCH IN A FLOW-BASED CONTEXT