K. ECONOMIC VIABILITY ASSESSMENT

The economic viability assessment (EVA) is a crucial but complex analysis which allows the assessment of the economic viability (under certain conditions) of existing or new generation, storage and demand response capacity in the electricity market. The ERAA methodology (see [ACE-11] Article 6) indicates that the EVA shall either assess the viability for each capacity iteratively or by minimising the overall system costs, where all capacities are optimised at once. This second method, minimisation of overall system costs, is considered in the ERAA methodology as a simplification of the EVA methodology. In this study, as in previous studies, the first method referred in the ERAA methodology, i.e. the assessment of the viability for each capacity resources, is considered. A full iterative approach is thus applied. For each iteration, the economic viability of all monitored capacities (or 'candidates') is evaluated following a selected criterion or metric. The details of this approach are presented in this appendix.

Elia has performed economic viability assessments in recent and past studies. In the Adequacy and Flexibility study of June 2021 [ELI-15], based on the introduction of the ERAA methodology as well as on the feedback received after the Adequacy and Flexibility study of June 2019 [ELI-16], several major improvements were introduced to make the EVA compliant with the ERAA methodology. These improvements included an extension of the perimeter to other countries than Belgium and the inclusion of additional capacity types to be considered in the assessment.

In the AdeqFlex'23 [ELI-0] **study the method** was **further improved starting from the previous approach with, amongst others, the novelty of making it a full multi-year approach. With the improvements applied to the multi-year methodology, the simulation of a large amount of climate years on an hourly basis, the inclusion of a large geographical perimeter; that study** remains**, to our knowledge, a trailblazer of adequacy and economic assessments.**

In addition, the hurdle rates are **also updated based on the latest study done by Professor K. Boudt of which a version is shared along** with the next AdeqFlex'25 study public consultation**. The updated calibration of the hurdle rate in EoM context follows the same methodology as the previous AdeqFlex'23 (see detailed methodology description below). The updated values are publicly consulted upon and consider recent market events and up-to-date data on revenues, costs and other relevant parameters.**

Finally, as in AdeqFlex'23, **Professor K. Boudt has also provided a calibration for the hurdle rates in context of the CRM reports.**

K.1. METHODOLOGY FOR THE EVA METRIC – UPDATE OF THE HURDLE RATES IN EOM CONTEXT

Basic principle

In line with the ERAA methodology, the metric for the economic viability assessment replicates as closely as possible the actual decision-making process undertaken by investors and market players. Given the high complexity surrounding such a multifaceted investment decision, the methodology for the economic viability assessment was developed as part of Elia's AdeqFlex'21 together with Professor K. Boudt. The methodology was based on an academic study published by Professor K. Boudt, which provides a theoretical and academic framework for investor behaviour [BOU-1]. The study further details how the theory can be applied when undertaking an economic viability assessment so that it is compliant with the ERAA. As part of the most recent AdeqFlex'25, Professor K. Boudt has updated the calibration of the hurdle rates following the same methodology as presented in the initial study (report to be found on the public consultation webpage).

Importance of risk aversion when modelling investor behavior

Professor K. Boudt's study begins with the need for a risk-averse approach when making investment decisions, substantiated via two theoretical frameworks that are well known in academic literature, i.e. utility theory and prospect theory. It follows from these frameworks that a risk-averse investor (their aversion to risk is a standard assumption in financial theories) always prefers to receive a given expected return with certainty over receiving the same expected return with uncertainties. These conclusions are particularly relevant for Elia's study, given the distribution of the simulated inframarginal rents, driven by (very) high spikes that occur with a lower probability and hence greater uncertainty. Where the methodology makes up for a wide variety of uncertainties and risks, in the end, the investment decision obviously remains the decision of an individual investor. Inherently, some modelling uncertainties unavoidably remain as it is impossible to fully mimic a complex investment decision.

Decision rule based on the WACC and the hurdle premium

According to the methodology, a capacity is considered as economically viable if the average simulated internal rate of return on a project exceeds the so-called hurdle rate:

Economically viable ⟷
Average internal rate of return >= *hurdle rate*

The average internal rate of return (IRR) and the way it is calculated as part of the overall process is further explained in Section 7 as part of the overall description of the process.

The hurdle rate is the threshold that the average project internal rate of return needs to equal or exceed for the project to be economically viable. The hurdle rate equals the sum of an industry-wide reference weighted average cost of capital (WACC) and a hurdle premium. All capacity (of any technology) is subject to the same WACC, whereas the hurdle premium differentiates between the technologies in accordance with the identified risks and uncertainties.

Reference WACC: A reference industry-wide WACC is calculated in line with the non-binding principles set in Annex 2 of the European methodology for calculating the value of lost load, the cost of new entry and the reliability standard. This includes the use of the well-known Capital Asset Pricing Model (CAPM) for the cost of equity (CoE) calculation:

$$CoE = r_f + \beta \times ERP + CRP$$

Where r_f is the long-term risk-free rate, β is the systematic risk of the reference investors, *ERP* is the equity risk premium and *CRP* is the country risk premium.

Taking into account the CoE, the real and pre-tax reference WACC is then calculated as follows:

$$WACC = \frac{1 + \left[CoE \times \frac{(1-g)}{(1-t)} + CoD \times g \right]}{1+i} - 1$$

with *g* the percentage of debt-based funding, t the corporate tax rate, *CoD* the cost of debt and i the expected inflation over the project's investment horizon.

Hurdle premium: The hurdle premium makes up for price risks going beyond the typical factors and risks covered by a standard WACC calculation. Adding such a hurdle premium is in line with ERAA Article 6, paragraph 9 (a) (iii), which states that 'a market-conform and transparent increase in the *WACC for these target years may be used to account for this price risk; the principles underlying the WACC increase shall be consistent with the WACC calculation guidelines from the CONE methodology*'. As pointed out in Professor K. Boudt's study, the main drivers for the level of the hurdle premium are the 'revenue distribution and downside risk', as well as the 'model and policy risk'. Also CEER, the association of European regulators, acknowledges these two principles on which the study of Professor K. Boudt builds.

Revenue distribution and downside risk covers for the non-normality of the return distribution, driven by the ranking in the merit order: The reference WACC calculation ignores the project-specific risk in terms of both the return variance and the non-normality of the return distribution. The effects for a typical risk-averse investor are significant, given the large deviations of the distribution of the project returns for electricity capacity from the normal. An important driver of the relative magnitude of non-normal behaviour and thus the 'revenue distribution and downside risk' is the occurrence of (extremely) high prices over the simulation horizon, dependent on the technology's ranking in the merit order. The capacities with lower marginal costs receive inframarginal rents more often compared to those with a high activation price. The investment case of such capacities with a high activation price depends therefore to a large extent on the occurrence of price spikes. In other words, the higher the activation costs, the fewer hours with actual inframarginal rents, so the more relevant it is that those more limited hours actually occur. Hence, for some technologies, the profitability crucially depends on the occurrence of (very) high prices during only a handful of hours, increasing the risk of such an investment. The calibration of the hurdle premium thus takes into account the discussed differences of position in the merit order in relation to the occurrence of inframarginal rents and differences of exposure to high prices across technologies.

The model and policy risk is technology-dependent and increases with the economic lifetime of the asset: When simulations are used to compute the expected project return and risk, model and policy risk inevitably exists. This is for example due to the non-linear dependence between the decisions of various market players (modelled as an iterative process), the long horizon of the investment, the international context of the electricity market, uncertainty about economic and energy policy, and the risk of regulatory and/ or policy-driven market intervention.

The electricity market context has proven to evolve quickly over the past few decades, as policy objectives have changed, changes to market design have been made, new approaches and interventions supporting policy objectives have been introduced, etc. The importance of this last risk driver has specifically increased compared to previous studies given the Belgian and European policy measures announced as a reaction to the high observed electricity prices. In Europe, also the growing importance of sustainability targets resulting in a drive to foster an energy transition, the upcoming digitalisation of the sector, emerging security of supply concerns, etc. are clear indicators of model and policy risks. Capturing these risks in a specific modelling set-up aiming to assess investor behaviour is, inevitably, never perfect. This is especially the case, given that the EVA is limited to the boundaries of using a single scenario by construction (in line with the European methodology). The base case scenario represents the best representation of reality, taking into account the expected energy policy, market design, consumer and producer preferences and no market interventions affecting the occurrence of (very) high price spikes. However, it is important to recognise the more nuanced and complex decision-making process of (risk averse) investors when using the model outputs to make conclusions on the economic viability via the hurdle premium. The calibration of the hurdle premium should therefore account for the impact of different scenarios on the profitability of the investment. The model and policy risk obviously increases over the economic lifetime of the technologies, as the related risks and uncertainties grow in importance with time.

Calibration of the hurdle rate was based on a combination of quantitative and qualitative assessment

As a first step to obtain a hurdle premium for each technology in the dataset, a reasonable range on the hurdle premium was set. The lower bound for medium and longer term investments (> 3 years) was set based on the values published in academic studies. In the study of Professor K. Boudt, the upper bound was fixed after discussions with market players, financial investors and fellow academics, which were complemented with numerical analyses.

FIGURE K-1 — CONSIDERED RANGE OF THE HURDLE PREMIUM

Next, the level of risk was set for the two risk parameters for every technology in the dataset, taking into account a qualitative and quantitative assessment. The higher the total perceived risk, the higher the hurdle premium that was applied for that technology. An overview of hurdle rates for the technologies in the dataset, based on the study from Professor K. Boudt, is presented with the investment costs in the Chapter 3 on scenarios and data of AdeqFlex'23.

K.2. METHODOLOGY FOR THE EVA METRIC – CALIBRATION OF THE HURDLE RATES IN CRM CONTEXT

The calibration of the hurdle rate in CRM context follows the same logic and methodology as described in the previous section and is again driven by the revenue distribution and downside risk, as well as the model and policy risk of an investment. However, for capacities with a CRM contract the hurdle premiums changes substantially because of the reduction in revenues uncertainty thanks to the additional and stable source of revenue coming from the CRM contract. Projects that receive a capacity remuneration combine revenues from two sources: revenues from the electricity markets (including inframarginal rents and ancillary income services) and from the capacity remuneration through the CRM framework.

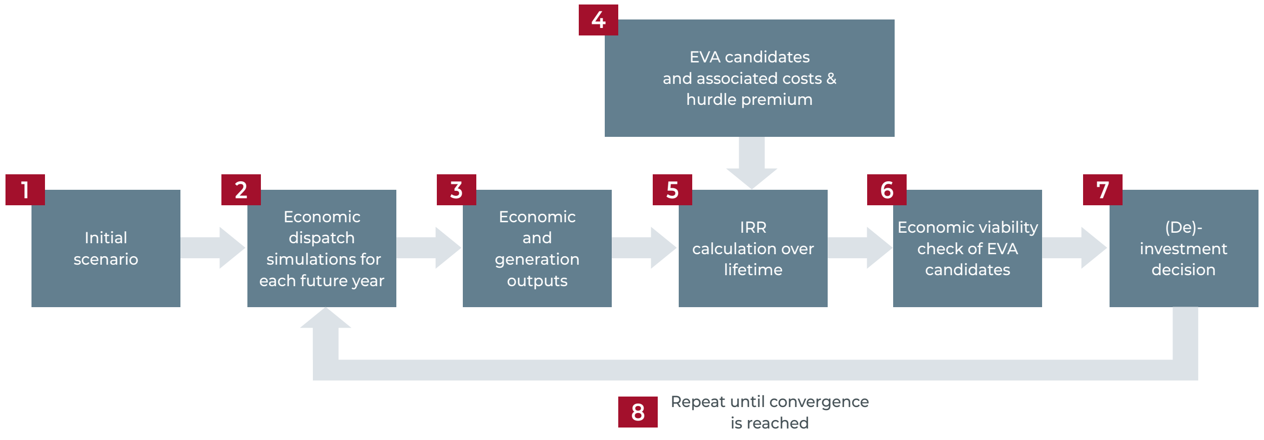
The uncertainty and thus the level of the hurdle premium for such an investor in a market design with CRM ultimately depends on the share of the received capacity remuneration compared to the total expected project revenues. The higher this share of stable revenues coming from the capacity remuneration, the lower the risk for investors and the lower the applied hurdle premium. The report on this new calibration exercise is also shared on Elia's website.

K.3. DESCRIPTION OF THE EVA PROCESS

Starting from a given scenario, the economic viability assessment of capacity (under different assumptions) is performed in a full multi-year approach. Indeed, as an investment today in new generating capacity can have a significant lifetime, investments in other capacities which become viable over this lifetime could impact the profitability of the investment decision made today. Vice-versa, investments made today can impact the profitability of future investments. Integrating these effects in an EVA assessment adds a new dimension to the optimisation. As in AdeqFlex'23, this new dimension is integrated by allowing the investor to choose in what year(s) to invest in additional capacity and subsequently simulating the full lifetimes of the considered investment decisions (possibly sampling from the closest simulated years in case not all years were simulated). This large set of investment-candidates is then optimised iteratively as a whole.

The process, which is illustrated in Figure K-2 is computationally intensive. For each iteration, the results of multiple market simulations in Antares are combined with simulation-independent economic parameters to generate a set of possible investment outcomes over the lifetime of a candidate. The set of returns is then used to calculate the Internal Rate of Return (IRR), a metric that can be used to gauge the profitability of the candidate. Following the approach proposed by Professor K. Boudt (see Section 1 of this appendix) investments decisions are then made and the models are updated.

FIGURE K-2 — OVERVIEW OF THE EVA PROCESS



K.4. INITIAL SCENARIO AND ECONOMIC DISPATCH SIMULATIONS 1 2

The initial scenario consists of a given set of installed capacities, consumption, demand flexibility and storage for each modelled zone.

The economic dispatch/unit commitment simulation is described in Appendix A. It is important to note that multiple hourly 'Monte Carlo' simulations are simulated for each future target year. This process is computationally intensive.

K.5. ECONOMIC AND GENERATION OUTPUTS 3

The market clearing price and generation (as well as consumption in case of storage) of each candidate are extracted from several simulations performed to cover its entire lifetime. Then, the revenues generated on the market are computed as the product of the market clearing price and the amount of energy delivered/consumed. Assuming that the capacities bid at marginal cost, the market bids are subtracted to obtain the inframarginal rents. In case of storage, no variable costs are assumed. For demand side response, a certain activation price is assumed. Finally, inframarginal rents are computed. In this calculation, startup costs are not considered, resulting in a possible over-estimation of the inframarginal rents.

As an example, this process is presented in Figure K-3 for a week in the simulation for a given unit. Inframarginal rents (for a unit without outages) can be presented in a simplified way on a yearly level as shown in Figure K-4.

FIGURE K-3 — CALCULATION OF INFRAMARGINAL RENTS OF INVESTMENT CANDIDATES: ONE WEEK PERIOD

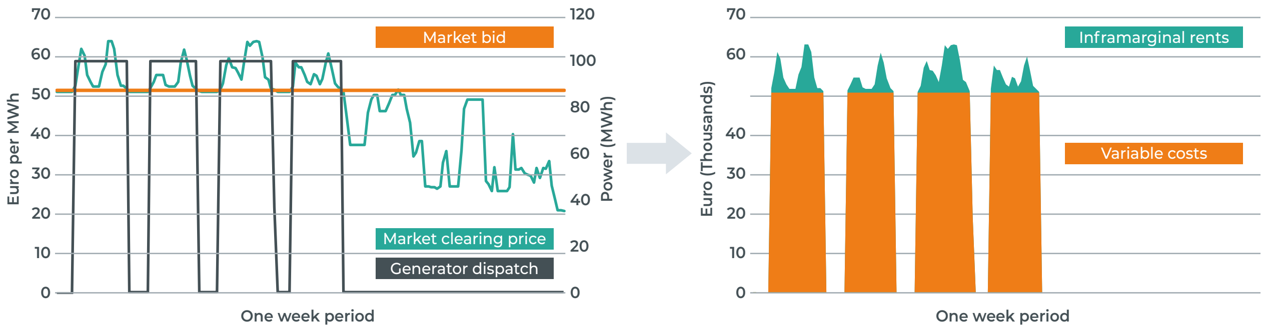
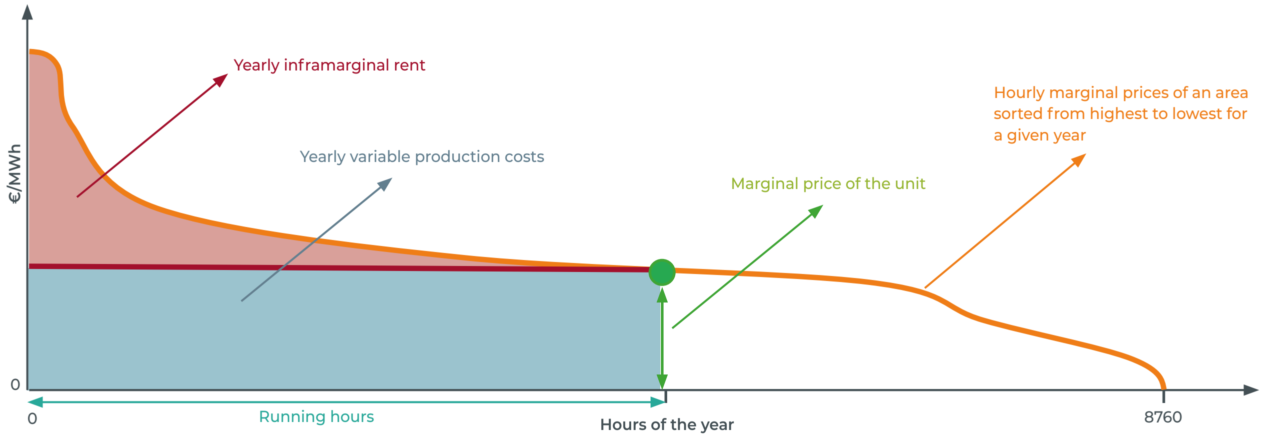


FIGURE K-4 — CALCULATION OF INFRAMARGINAL RENTS OF INVESTMENT CANDIDATES: SIMPLIFIED OVERVIEW OF A ONE YEAR PERIOD



To take into account possible increases in the market price cap, two additional indicators are considered from the market simulation. On one hand, the amount of energy delivered by the candidates during times when the price is at the price cap of the simulations is extracted. On the other hand, for each possible future price cap, the number of times this price cap would be increased during a given 'Monte Carlo' year is also analysed. To mimic future price cap evolutions, the ACER-approved new 'SDAC Harmonised Maximum and Minimum Clearing Price methodology' (HMMCP methodology) of 06/01/2023 is taken into account. Starting from the initial price cap, if a triggering event (as defined in the HMMCP methodology [NEM-2]) is observed, the revenues generated by the plant in (near) scarcity are adapted to reflect the actual sampled price cap.

As stated in Annex 1 of the 'HMMCP methodology', the price cap will be adapted according to the following rules:

a. 'the harmonised maximum clearing price for SDAC shall be increased by 500 EUR/MWh in the event that the clearing price, in at least one bidding zone, exceeds a value of 70 percent of the harmonised maximum clearing price for SDAC in at least 2 market time units in at least 2 different days within 30 rolling days from the first price spike;'

b. 'after the event referred to in subparagraph (a) occurred, the transition period shall be set to 28 days following the completion of the event;'

c. 'during the transition period mentioned in subparagraph (b), the clearing price shall be kept at the value of the harmonised maximum clearing price for SDAC before the adjustment and all events referred to in paragraph (a) occurred during the transition period shall be ignored;'

d. 'the bidding zones referred to in subparagraph (a) shall be only those bidding zones with cleared buy and sell volumes and those part of the fully coupled SDAC, excluding virtual zones and uncoupled bidding zones.'

In case no simulated years were available for a given moment in the candidate's lifetime, the revenues were randomly drawn from the closest available years, depending on their proximity to the target year.

K.6. EVA: ADDITIONAL REVENUES 4

To determine the economic viability of an investment candidate, an estimation of the costs incurred, and revenues generated from the moment the decision to invest is made until after its (de-) commissioning needs to be performed. Some of these costs and revenues, like the revenues on the electricity market, depend on the market situation that will actually materialise. It is these uncertain revenues and costs that are estimated using a detailed simulation of the electricity market as explained in Sections 4 and 5 of this appendix. Cash flows like the investment costs and fixed operational and maintenance costs, are assumed as 'known' at the start of the candidates' lifetime.

Other revenues (other than electricity market revenues) are also taken into account in this assessment. These are described in the sections below.

Net Ancillary services revenues

Capacities in the energy market can potentially earn net additional revenues by participating to ancillary services. However, these (net) revenues are not modelled within Antares. Hence, Elia has to estimate these net revenues that market actors may potentially earn on top of the simulated energy market revenues.

In the remainder of this section, only frequency-related ancillary services are considered. Other services such as black start, voltage control and congestion management, are assumed to be remunerated in a cost-reflective manner, not generating additional net revenue that should be further accounted for.

In order to perform the required estimation for net balancing revenues, Elia relies on the existing methodology used for each calibration cycle of the Capacity Remuneration Mechanism that calculates net balancing revenues based on reservation costs of these services for the latest 36 months. When doing so, Elia is of the opinion that market actors must consider additional aspects to account for potential arbitrage between energy and balancing market and the associated opportunity cost of being present in one market against the other.

Therefore, Elia considers the same approach than the one considered for the CRM calibration to calculate **net revenues starting from the revenues** earned from the provision of balancing services, while considering some differences highlighted below:

- Elia looks at reservation costs for the latest 36 months for balancing services.
- Elia considers the following principles for the different balancing products when going from **gross** balancing revenues to **net** balancing revenues:
  - For FCR, aFRR and mFRR, Elia considers that the estimation made should:
    - take into account the foreseen trend regarding the volume of capacity and the mix of technologies able to provide such services and the potential evolutions of the prices of these products;

      consider cost assumptions to deduce running, start-ups and operational costs for each technology;
    - deduce from direct costs and market prices opportunity costs, for each technology in activation and reservation;

Generation from heat or steam

In order to assess the additional revenues that CHP units could generate from combined heat and power generation, the method applied by Fichtner in their study entitled 'Cost of Capacity for Calibration of the Belgian Capacity Remuneration Mechanism' published in April 2020 [FIC-1] is applied. Such a method - which is called 'CHP credit' - considers a reduction of the variable costs of the CHP units for their dispatch decision in the electricity market. By reducing the variable cost at which the unit is dispatched, it increases the margin that such units would make (based on electricity market revenues and the decreased variable costs), which mimics the additional revenues they would get from selling heat or steam.

The CHP credit is built upon the reasoning that heat needs to be generated for a certain process and that if not provided by the CHP, it would be provided by a gas boiler. The benefit in marginal cost for the CHP is therefore the 'avoided' cost of generating the same amount of heat with a gas boiler. Elia assumes an overall efficiency (electricity and heat) of 90%. The ratio of thermal power (MW_th) to electrical power (MW_el) is defined according to the electrical efficiency of each CHP unit.

Depending on the gas and carbon prices, the 'CHP credit' is calculated and then subtracted from the CHP marginal cost. The heat and steam revenues are therefore taken directly into account in the 'electricity market' revenues calculated by the model.

Even if such an approach takes into account the benefits of combining heat and power generation, the detailed gains will greatly depend on the supplied process (heat generation, steam generation, industrial process, heat/steam profile required…) and on a case by case basis, the resulting benefits could greatly vary.

As also observed when analysing historical dispatch decisions made by CHP units, there is quite a number of CHPs still running when electricity prices are low (below their variable costs). During such moments, it is possible that those units might not make any profit or even present losses on the electricity market.

Other revenues

Finally, it is important to note that no other subsidies are taken into account and hence all units that are 'policy driven' or that are expected to get subsidies are outside the scope of the economic viability assessment. This concerns:

- coal and lignite generation (as they are mostly policy driven): although their profitability is under pressure, their economic viability is not assessed.
- nuclear units which are assumed to be policy driven;
- RES generation (biomass, wind, PV, hydro), as they get subsidies and it is assumed that the authorities will put in place a framework to achieve the targeted capacities set in the NECP.

K.7. IRR CALCULATION 5

The methodology to determine the metric on which each technology/capacity is assessed is developed by Professor K. Boudt. In accordance with this methodology, a technology is considered economically viable if the average projects' Internal Rate of Return (IRR) exceeds the hurdle rate. This section further elaborates on the IRR calculation based on the costs, the revenues and the economic lifetime of the asset.

For each simulation result in the dataset, the **internal rate of return** is calculated as the rate R for which the net present value of the sequence of cash flows equals zero:

$$NPV = -I + \sum_{t=1}^{K} \frac{IR(t)}{(1+R)^t} = 0$$

As the formula above illustrates, the main drivers for the expected internal rate of return are:

- **Costs *I***, which represents the outflow of cashflows to **cover all fixed costs** foreseen over the economic lifetime of the asset:

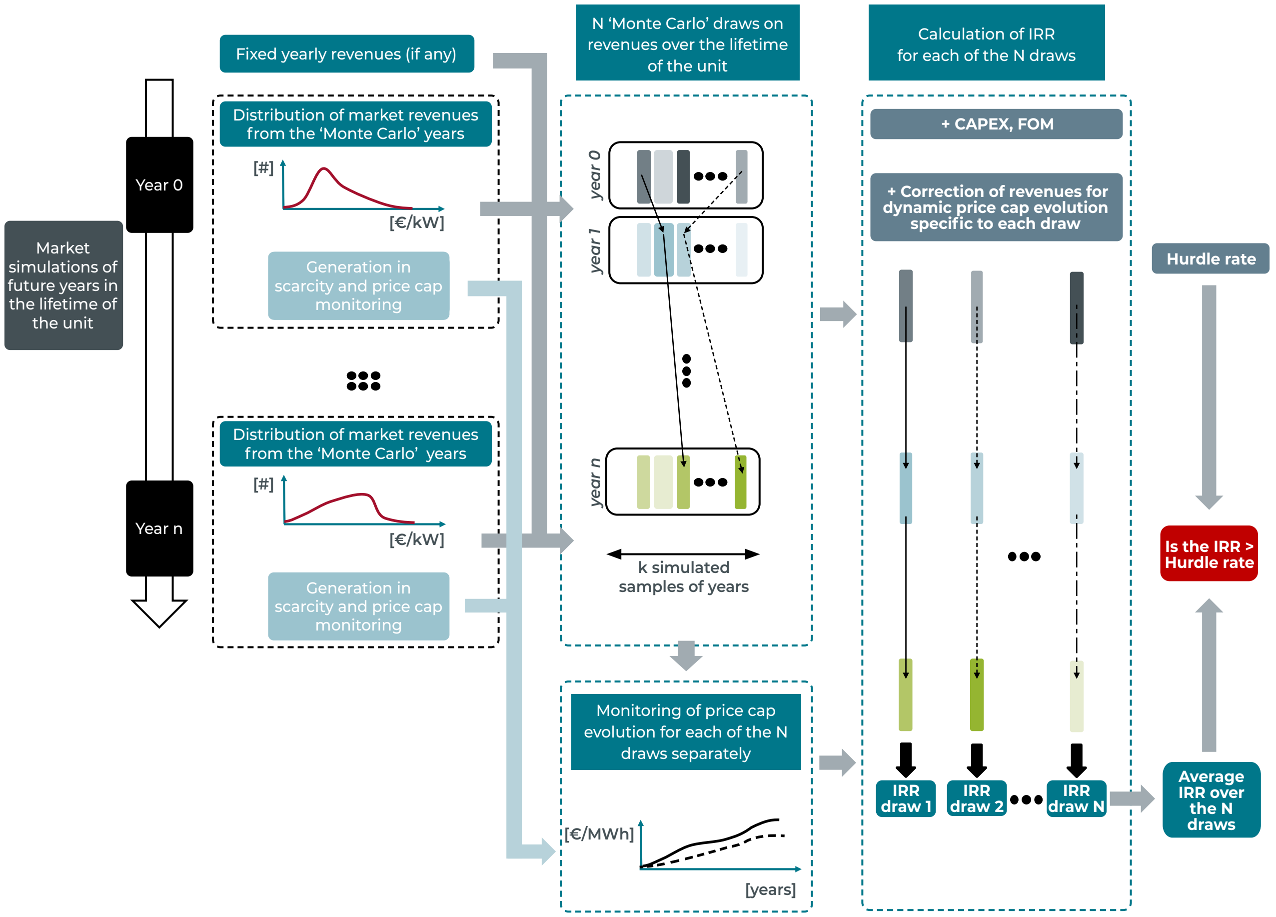
$$I = CAPEX + \sum_{t=1}^{K} \frac{FOM}{(1 + risk - free\ rate)^{t-1}}$$

These include the fixed costs in terms of capex and FOM, which are assumed to be known at the moment of the investment decision. These input parameters are detailed in the present study in Chapter 3 on scenarios and data.

- **Inframarginal Rents (*t*) :** The inframarginal rents over the lifetime of the asset are taken into account. These are a result of the economic dispatch simulations (see also Section 5 of this appendix). There may be years in the full economic lifetime of the unit where no simulation is available. In this case, the year is drawn randomly from the two closest years for which simulation data is available with a weight proportional to their 'closeness' to the target year.
- **Economic lifetime of the asset *K*:** The time (in years) the unit will be active in the market following the decision to invest.

The project IRR is calculated for each sampled lifetime, after which the average value of the simulated project IRRs over the different sampled lifetimes is applied in the decision rule. It is important to note that an investment in new capacity could happen at any moment in the future. For this study, a major update was done where the investment decision could happen during any relevant year in the study horizon. In practice, this means that for a unit single ten or more investment candidates could exist (one for each relevant future year) and hence could result in ten or more IRR's being calculated (one for each study candidate). A schematical representation of the process for sampling the IRR of a single unit for a single target year is represented in Figure K-5. In practice this process was hence repeated for every investment candidate and for each of the target years in which an investment decision was to be made.

FIGURE K-5 — CALCULATION OF THE IRR FOR ONE INVESTMENT DECISION FOR ONE EVA CANDIDATE



The current value of 4,000 €/MWh is taken as starting value for price cap of the European day-ahead market. This price cap limits the profit energy producers can make at times of scarcity. When considering an investment in the electricity market, investors might want to take into account the possibility that this price cap increases during its lifetime. Since it is impossible to know in advance which of the climate years will occur and in what order, the simulations are first performed with an initial market cap and the correction for the over- or under- estimation of revenues is performed in a second step. To estimate what correction is needed for a given year, the number of MWh generated in scarcity are counted. Those are multiplied by the difference between the actual price cap (taking into account price cap increases due to scarcity events) and the price cap set in the model. In theory, the price cap could increase over time until it is high enough to cover the Value of Lost Load (VoLL). Estimations on the VoLL vary greatly but could easily reach ranges from 10,000 to 20,000 €/MWh and beyond, depending on the estimations and the applied methodology. In this study, the maximum final price cap was set to 20,000 €/MWh.

K.8. ECONOMIC VIABILITY CHECK OF EVA CANDIDATES AND (DE-)INVESTMENT DECISION 6 7

According to the methodology, a capacity is considered viable if the average simulated internal rate of return of a project equals or exceeds the hurdle rate of the technology:

Economically viable ⟷ *Average internal rate of return ≥ hurdle rate*

The average internal rate of return is calculated as the output of step 6. The hurdle rate is set in accordance with the methodology developed by Prof. K. Boudt, as presented in Section 1 of this appendix.

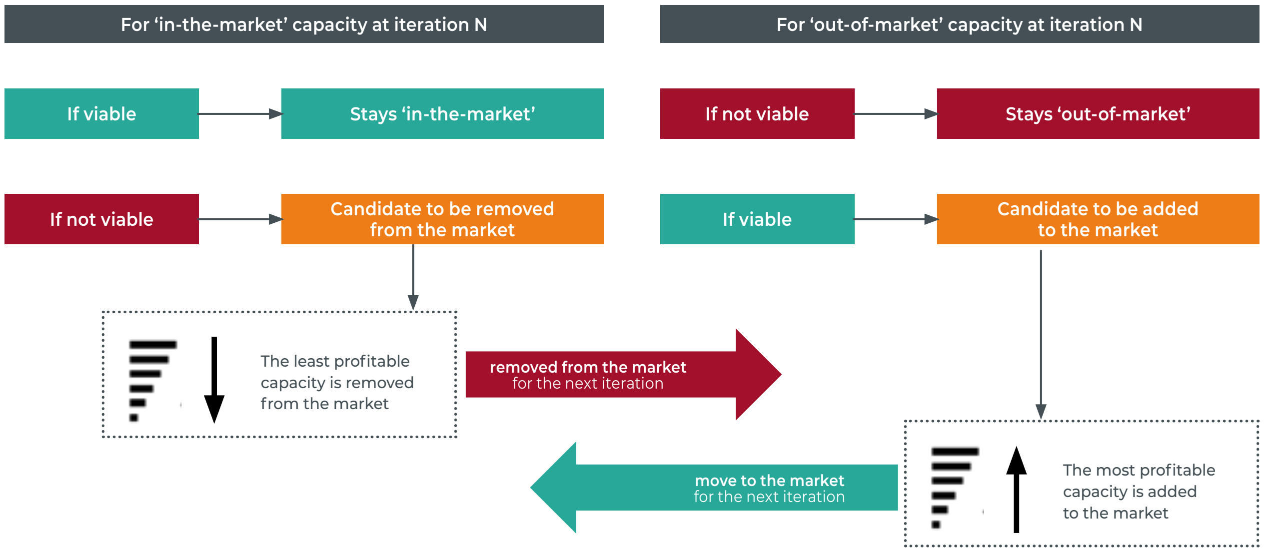
Such a check is performed for all candidates considered in the EVA loop and during each iteration of the loop. At each iteration, the decision to add or remove a capacity to/from the market is undertaken as follows (see Figure K-6 for an illustration of the process):

- For a capacity that is assumed 'in the market' in a given iteration:
  - if economically viable, then it remains in the market;
  - if not economically viable, then it is considered for possible removal from the market in the next iteration.
- For a capacity that is assumed 'out-of-the-market' in a given iteration (including any new capacity):
  - if not economically viable, then it remains 'out-of-the-market' (or it is not invested in, in the case of new capacity);
  - if economically viable, then it is considered for possible inclusion in the next iteration.

The investment and de-investment candidates are sorted from the most profitable to the least profitable. The investment decision for the next simulation step consists of adding the more profitable capacities (back) 'in the market' and removing the ones that are 'in the market' but are the least profitable.

To ensure the convergence of the results, only a limited number of candidates is moved from 'in-the-market' to 'out-of-the-market' status within each iteration. As investment decisions can be made for multiple target years, there is a cap on the maximum capacity that can be invested in per unit over all the target years in an iteration.

FIGURE K-6 — DECISION PERFORMED AT EACH ITERATION OF THE EVA LOOP FOR EACH CANDIDATE



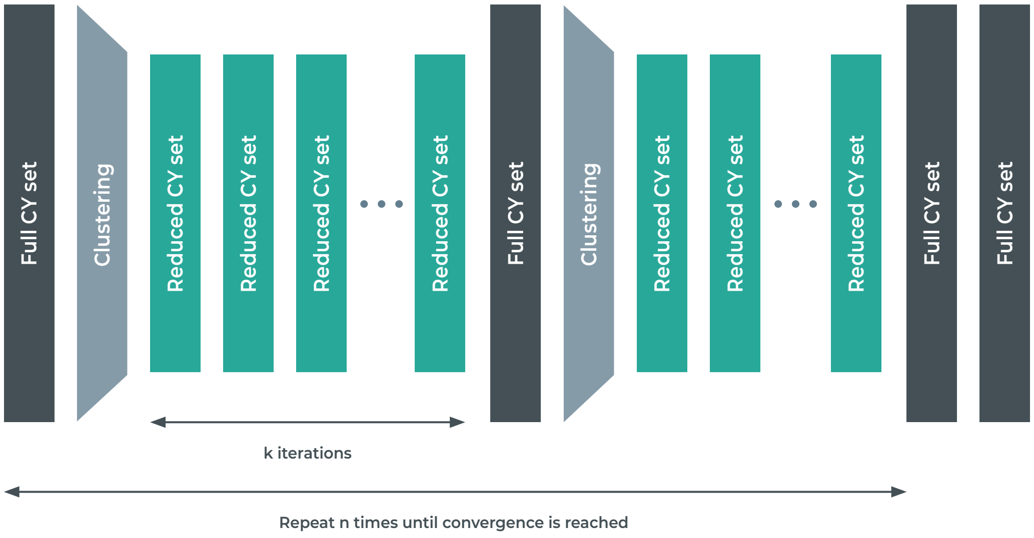
K.9. PROCESS/LOOP ITERATION 8

Tens of such iterations are needed to end up in a situation where all viable capacity is in the market and all non-viable capacity is out of the market. Given that these simulations are computationally intensive, reducing the computational expense of each simulation (by for example limiting the number of 'Monte Carlo' years simulated) significantly reduces the time needed to get a final result. To minimise the loss of information when selecting 'Monte Carlo' years, these are clustered based on the revenues generated by capacities within full adequacy simulations (which consider 200 climate years and several outage patterns of thermal units and selected interconnectors outages, applying the flow-based approach and taking into account the so called 'adequacy patch' rules). This clustering is performed using the k-medoids method. There is no reason this is the only viable method, but one advantage is that it provides medoids naturally, whereas medoids would have to be calculated afterwards when using for example the hierarchical clustering method.

For each of the clusters, only the medoids are then simulated in subsequent simulations. Each of the medoids has a weight applied to it, in proportion to the size of the cluster it represents, which is then used in the calculation of the relevant indicators. As the situation changes at each iteration, the original clustering could lose its relevance after several steps. To avoid this from happening, a full set of 'Monte Carlo' years is re-simulated after a given number of iterations (k). The clusters are then recreated based on the outcomes of this simulation.

Finally, to ensure that the final results are robust to the full set of 'Monte Carlo' years, the iterative approach is concluded with a 200 'Monte Carlo' year simulation. While some small changes in economic viability could still have occurred at this point, those are limited and are usually resolved after two or three additional full simulations. As the final results are validated with respect to the full climate year set, the validity of the results does not depend on the clustering method.

FIGURE K-7 — EVA LOOP: SET-UP OF THE ITERATIONS

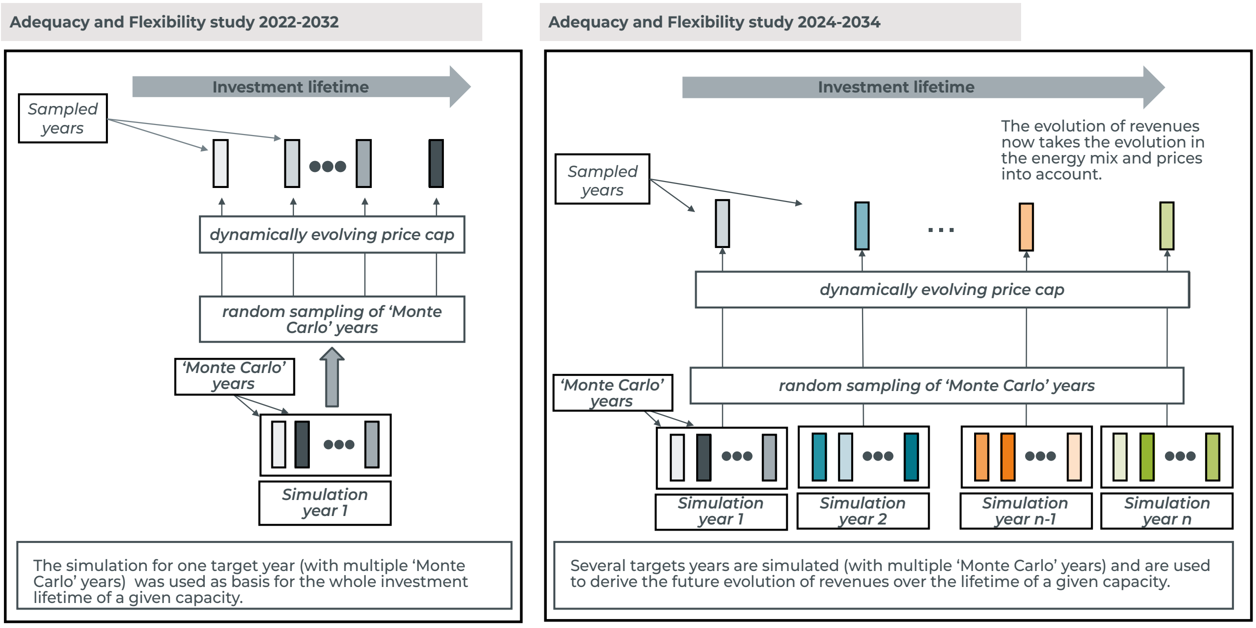


K.10. IMPROVEMENTS IN MULTI-YEAR REVENUE CALCULATIONS

Future investment decisions may impact the profitability of an investment made today and investments made today may impact the profitability of future investments. Therefore, properly assessing the dimension of time was identified as one of the next big steps forward in performing an EVA for the present study. Therefore, a significant refinement is made with regards to the previous methodology concerning the estimation of costs and revenues throughout the lifetime of the unit. This change in process is schematically represented in Figure K-8. In Elia's AdeqFlex'21 study, the evolution of profits throughout the lifetime of the unit was taken into account through the evolution of price caps. Practically, this meant that for an investment decision in year 1, only year 1 was simulated. By letting the price cap evolve dynamically, sample future years in the lifetime of the unit were generated. Consequentially, the energy mix considered did not evolve. The method used in this study explicitly considers future energy mixes that may occur during the lifetime of the unit. To achieve this improvement, the economic lifetime of each candidate is assessed based on a sequence of economic dispatch simulations in a multi-year approach. In case no simulation is available for a future year in the lifetime of the unit, the year is drawn randomly from the closest years for which simulation data is available with a weight proportional to their proximity to the target year. In the figure this is represented for the investment decision for a unit in year 1. The changing colours represent a change in energy mix.

With the inclusion of a full multi-year economic viability assessment, this study is a front-runner in economic viability assessments for adequacy and economic studies.

FIGURE K-8 — SCHEMATIC REPRESENTATION OF THE FULL MULTI-YEAR ECONOMIC VIABILITY ASSESSMENT



Unsimulated years “filled” by post-processed nearby simulated years

As investment/disinvestment decisions may be made in any future year, several options are available to decision makers. In the present study Elia allowed investment/disinvestment decisions in each of the years under study i.e. allowed for decisions in years between 2026-2036. As such, multiple possible decisions were assessed in each iteration of the investment loop.

Allowing investment/disinvestment decisions over the 10 years period of the assessment (2026-2036) seems more appropriate than approaches based the reduction of the decision horizon from the full 10 years period into several overlapping steps of a reduced number of years in length. The latter approach is typically used due to the difficulty of solving the EVA problem as a full stochastic system costs minimisation in a single run. Furthermore, in order to reduce the problem to a computationally tractable form, a reduced number of climate years might need to be considered as well. Such approaches might lead to myopic decisions, as every time step typically needs to be considered in isolation from the subsequent ones. Furthermore, the use of a reduced number of climate years will/might cause the results not to be statistically robust.

Thousands of revenue values are calculated in this study at each iteration step by use of full hourly economic dispatch simulations applying the flow-based approach and taking into account the so called 'adequacy patch' rules. The consideration of many climate years in the EVA step ensures statistical robustness of the results. The use of full hourly economic dispatch simulations, as mentioned above, ensures consistency between the EVA results and the adequacy results, e.g. with respect to the quantification of adequacy indicators LOLE and EENS.

Figure K-9 shows, as an illustration, some decisions available to investors in new units and owners of existing units. The overall procedure is as follows:

- A global list of candidates is defined, so for each year of the assessment y = 1 (2026) ... 11 (2036), individual candidates per technology subject to EVA are defined for each country (market area) considered e.g.;
  - Invest in technology candidate T in year 1 , ...,technology candidate T year 11 in country (market area) X
  - Decommission technology candidate T in year 1, ..., technology candidate T year 11 in country (market area) X
- In each step of the iterative approach, a selected number of the most profitable investment decisions and a selected number of the most unprofitable decommissioning decisions are chosen. It is important to note here that the procedure considers the calculation of thousands of revenue values at each iteration step. This is necessary in order to ensure statistical robustness of the indicators used to assess the viability of the candidates within each iteration step.
- The final 'decision' is passed into the simulation chain, the invested and decommissioned candidates are updated in the model and a new simulation is then performed.
- The previous step of simulation and further selection of the most profitable new investments and removal of the most non-profitable existing units is repeated iteratively until convergence is reached.
- In order to ensure both statistical robustness and computational performance, clustering of 'Monte Carlo' years, based on the revenues generated by capacities within full adequacy simulations, is considered within the intermediate iterations of the approach. The clustering is revaluated and clusters are recalculated after 'k' iterations, where k < n, and 'n' is the typical number of iterations needed to reach convergence.
- Convergence is characterised by a situation in which no more investment candidates are profitable and no more decommissioning candidates are unprofitable. In this situation the so called 'long-term equilibrium' has been reached.
- The long-term equilibrium is also characterised by
  - "IRR — hurdle rate" = 0 for new investment candidates for which some capacity was invested.
  - "IRR — hurdle rate" < 0 for new investment candidates for which no capacity was finally invested.
  - "IRR — hurdle rate" ≥ 0 for existing capacity which is not decommissioned and remains in the market.

    "IRR — hurdle rate" < 0 for existing capacity (when considering their investment) which has been decommissioned and leaves the market.

In some limited cases oscillations in the decision of some candidates (for example in and out again) might occur at the end of the full EVA loop. In these cases the solution where all capacity remaining in the market is viable is chosen.

FIGURE K-9 — EXAMPLE OF INVESTMENT OPTIONS CONSIDERED IN THE EVA

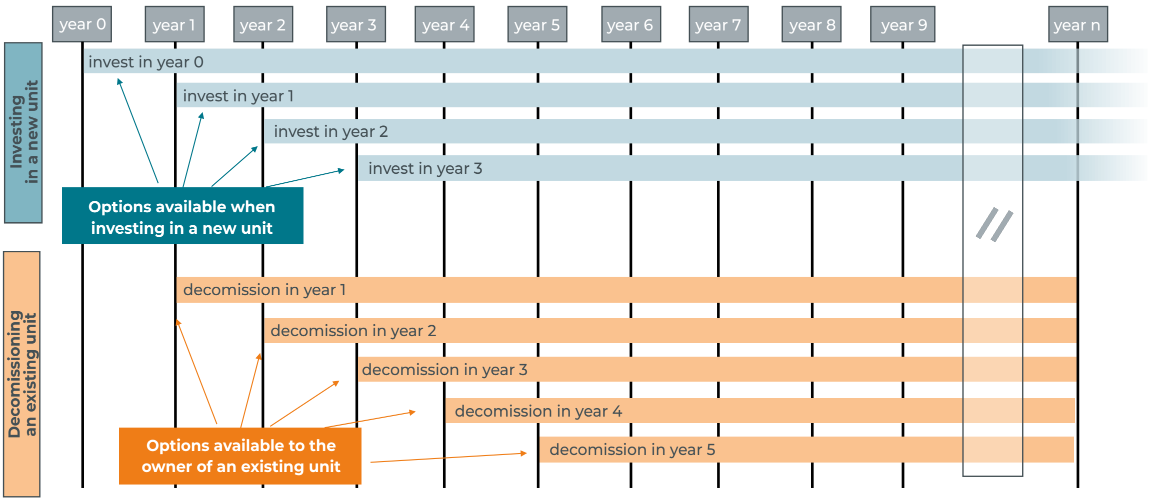
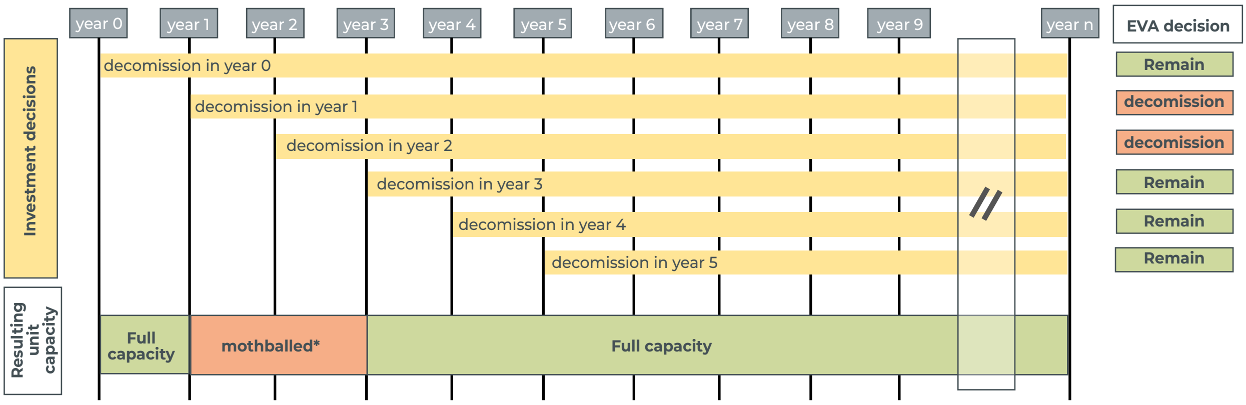


FIGURE K-10 — ZERO COST MOTHBALLING IN THE PRESENT STUDY



* when a unit is mothballed/decomissioned, it remains in the model with a minimal capacity (1 MW) to evaluate its economic viability in future iterations

Figure K-10 shows how mothballing-demothballing decision are assessed in the present study.

Within the 10 years of the analysis, a given decommissioning candidate can undergo a 'mothballing → demothballing' transition if e.g. its viability is negative during several consecutive years. In Figure K-10 this is illustrated as follows: i) the unit is mothballed in year 1, remains mothballed in year 2 and it is demothballed in year 3. Since the procedure considers the calculation of thousands of revenue values probabilistically, it is important to notice that such 'mothballing-demothballing' transitions as illustrated in the figure need to occur structurally (i.e. enough times probabilistically speaking) in order to appear as a 'final' mothballing/demothballing decisions at any given iteration. In this approach no costs for (de-)mothballing are considered. In case such mothballing is observed in the final result, additional iterations with cost estimates are to be considered.