Model-based approach to assess the future economic viability of power plants through expected producer revenues and costs

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***Abstract*–Assessing the economic viability of power plants is an essential precondition to correctly analyse the resource adequacy of the future power system, especially in the context of the energy transition. EU legislative initiatives like Fit-for-55 and REPowerEU, are expected to significantly increase the share of renewables over the coming years. Since these sources have lower variable costs, renewables are gradually reducing the existing thermal units running hours without affecting the energy price. The intensification of this phenomenon will lead to a progressive decrease of their profit margins, hence increasing the risk of thermal capacity being decommissioned for economic reasons. This paper shows a novel methodology to assess the economic performance of generators based on expected producer revenues and costs. It was adopted for the Italian Resource Adequacy Assessment of 2023, and the results indicate a significantly higher decommissioning compared to the approach implemented in the European Resource Adequacy Assessment of 2023, which takes the perspective of a central planner with perfect foresight that minimizes the total system costs.**

Index Terms—economic assessment, electric system, forecasting, market simulation, adequacy assessment

I. INTRODUCTION

Ensuring a reliable power system means having sufficient power plants and other capacity resources in the system to meet the electricity demand at all times while complying with safety and quality of service requirements. Transmission System Operators typically assess the electricity resource adequacy by simulating the future power system based on scenario assumptions of how much capacity will be available to meet demand and employing Monte Carlo analysis to capture uncertainty [1][2]. As required by EU Regulation, an adequacy assessment that identifies adequacy concerns is a necessary condition for implementing a Capacity Remuneration Mechanism (CRM). Such a mechanism aims at economically incentivizing market participants to keep resources in the market and, when needed, to build new resources, with the overall objective that sufficient resources are available to ensure system adequacy.

Regarding the adequacy assessment, it is important to point out that the resources present in the scenario must be able to cover their costs, otherwise existing plants may retire and new ones will not be built[3]. Thus, being able to perform robust economic viability assessment (EVA) of power plants can be a useful tool for checking the plausibility of future power system scenarios and help in identifying potential risks to resource adequacy in the medium to long term.

With the EU Clean Energy Package[4][5][6][7], the European Commission has mandated the European Network of Transmission System Operators for Energy (ENTSO-E) to perform a European Resource Adequacy Assessment (ERAA)[8][9][10] including the so-called Economic Viability Assessment (EVA) of power plants, which aims at determining the commissioning and decommissioning of system resources based on their economic performance. In a nutshell, the EVA aims at simulating the electricity market in a given scenario to determine the dispatch of resources, as well as their revenues and costs. The results can therefore be used to identify the amount of capacity at risk of becoming economically unviable, as well as the technologies that may be susceptible of new investment, allowing to obtain the long-term system configuration. The system resulting from EVA is then analysed to identify potential capacity shortages in comparison to the expected demand.

The ERAA methodology approved by ACER gives ENTSO-E the choice between two approaches that can be employed to perform an EVA: a system cost approach

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and an approach based on expected producer revenues and costs. The first takes the point of view of a central planner, aiming to minimize the total system cost, regardless of the profitability of single power plants. The latter methodology takes the perspective of power producers who assess the performance of their own assets.

Until the 2023 edition of the ERAA, ENTSO-E has exclusively used the system cost approach to perform the EVA, detailing its implementation inside the report. However, having a system-wide perspective, this approach may not effectively simulate a real-world investor behaviour or accurately assess potential technology expansion. In this paper, we are proposing an alternative EVA implementation based on expected producer revenues and costs that has been developed to better capture the economic dynamics that trigger the evolution of the power system resources. A more realistic forecast of this evolution is the essential starting point to identify adequacy issues in a more reliable and robust way.

In the following, the new framework for assessing the economic viability of different types of capacity resources is presented. This framework is based on the maximization of the revenues made by generation sources, which are obtained through an iterative simulation of the electricity market. In each iteration the revenues are compared to fixed costs of the Production Units (PU) for existing capacity, and, for potential new capacity, also to the Cost of New Entry (CONE). This allows to directly establish the profitability of the PUs and hence apply economic logic to estimate potential retirements or new investments by market operators.

The challenge consists in capturing the revenues over a wider time horizon and not just a single year. In fact, the methodology applied to a single future Target Year (TY) is described at first. Then it is adapted to a whole Time Horizon (TH) composed by several TYs where for each PU the assessment of a real business plan is simulated. In order to do so, the decisions taken in every TY consider the expected economic performance of the PU also in the following ones.

II. STARTING SYSTEM

A. *Electricity market simulation*

For the scope of this paper, the electricity market has been simulated employing the commercial tools Plexos[11] and BID3[12]. However, any market simulating tool can be used as long as it returns the economic performance of the PUs. We model a system composed by 74 Bidding Zones (BZs) linked by interconnections. A specific load is assigned to each BZ which will be fulfilled either by the PUs in the same BZ or by PUs located in neighbouring BZs, depending on economic variables (e.g. offered price) and technical constraints (e.g. transport capacity). These are the minimum features required by the model. The system is characterised by scenarios that are expected to unfold in the future. The uncertainty thus introduced becomes a factor of the whole analysis. The simulation yields an hourly price per BZ, as well as the dispatch of PUs. This information is needed to calculate costs and revenues per PU.

PUs are divided in two main categories: dispatchable and nondispatchable. NondispatchablePUs cannot be modulated: their generation must be fed into the system when it occurs (or curtailed when in excess) but cannot be ramped up in case additional power is needed. Renewables, such as photovoltaic and wind generators, fall in this category. In fact, the production of those PUs is bound to external uncontrollable factors connected to the weather. Different Weather Scenarios (WS) can be considered to account for several possible operating conditions of the power grid. The results of the related market simulations are then averaged using weights representing the expected likelihood of their occurrence. Instead, the operation of dispatchable PUs can be controlled and therefore adapted to the necessity of the load netted from the nondispatchablegeneration. Those PUs participate to the electricity market in order to produce an economically efficient offer/demand equilibrium. In general, most of the traditional installed capacity is configured as dispatchable and the players who own it have the minimum objective of keeping it economically sustainable.

B. *New entry capacity*

The approach is able to identify new entry capacity, which represents dispatchable PUs that currently are not part of the power system but could be built in the future thanks to favourable economic conditions presented by the market. When assessing the possibility of these units actually entering the system, investment costs need to be taken into account in addition to the ones considered for the existing capacity (e.g. maintenance, insurance, …). In economic terms, this is referred to as the “Cost of New Entry” (CONE). As part of the Clean Energy Package, ACER has defined a methodology on how to assess the CONE[13], leaving it to Member States to determine a representative CONE value at national level and a potential volume of new entry capacity. Given a specific technology, the maximum amount of new capacity that can be realistically built in a BZ is called expansion potential. In order to make existing and new capacity compete in the electricity market on equal ground, the presented EVA methodology considers a system already enlarged to the full expansion potential. In this way, the market simulation returns the performance of each PU, both existing and expanded, based solely on its ability to recoup costs. Then, the related revenues can be employed to reproduce the investors decisions considering the PU specific costs. The starting system is hence obtained by adding to each BZ as much standard candidate PUs of a fixed capacity (e.g. 100 MW) as to saturate the expansion potential of that technology. Only the expansion of thermal capacity is assessed in this paper, but the flexibility of the methodology allows to easily extend the analysis to other technologies.

III. METHODOLOGICAL APPROACH: ITERATIVE PROCESS

The iterative process is schematically reported in Fig. 1. The simulation of the electricity market considers one year of operation, which is the TY. In the following, the steps of the procedure are explained in detail.

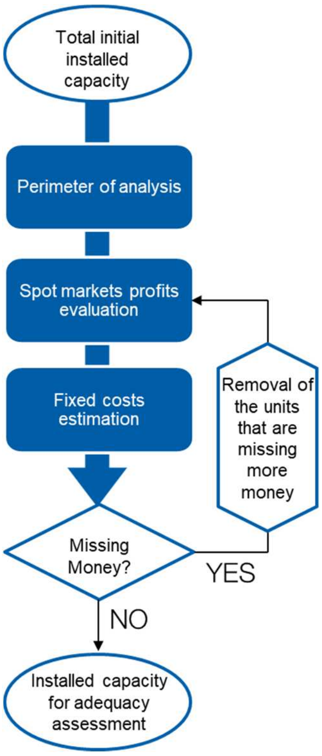

Figure 1. Iterative process flow chart

A. *Perimeter of analysis*

The first step is to define a perimeter of the analysis. It is possible that only a subset of the existing thermal PUs in the system are subject to the EVA. In general, the following categories may be excluded:

- Policy units. If the existence of a PU is protected by a policy, its economic performance is not relevant to its permanence in the market.
- Incentivised units. Some units may receive incentives on top of the market revenues, making them therefore extremely unlikely to become economically unviable.
- Units incorporated in industrial processes. If the main purpose of a PU is not to make profit on the electricity market, but to provide energy and potentially also heat to an industrial production process, its decommissioning would not necessarily depend on the revenues gained from electricity markets.

The remaining units are all existing thermal PUs whose economic sustainability is solely linked to the revenues obtained from the electricity market, which is the object of the simulations performed in the methodology. The perimeter of the analysis is composed by them and by the standard candidate PUs added to the system to consider the expansion potential. All this capacity distributed among several BZs will compete on the same electric market.

B. *Electricity market simulation*

Given the starting system, the procedure consists of several market simulations[10][11] performed iteratively. At each iteration the resulting revenues of each PU in the perimeter are compared to their costs, thereby computing its Earnings Before Interest, Taxes, Depreciation, and Amortization (EBITDA [€]). This number is then divided by the capacity of the PU in order to obtain a unitary EBITDA (EBITDAu [€/MW]) that allows to compare its performance to the one of the other PUs. The equation to execute this calculus varies from real PUs to standard candidate ones because of the costs that need to be taken into consideration:

- Real PU:

$$EBITDA_u = \frac{Revenue - FOM \times Capacity}{Capacity} \qquad (1)$$

- Standard candidate PU:

$$EBITDA_u = \frac{Revenue - Capacity \times (CONE)}{Capacity} \qquad (2)$$

  - Revenue: gross margin resulting from the market simulation [€]. It considers profits and variable costs (e.g.: CO_2 and fuel costs).
  - FOM: Fixed Operational and Maintenance costs [€/MW].
  - Capacity: installed capacity of the considered PU [MW].
  - CONE: Cost Of New Entry comprising CAPEX and operating expenses [€/MW].

If a PU has EBITDA<0 it is said to be missing money. A portion of the missing money capacity is considered decommissioned and removed from the system that will be simulated in the following iteration. Hence the remaining PUs will see lower competition on the electricity market, obtaining higher revenues. This makes the PUs that previously were only slightly unprofitable to became profitable. The procedure ends when all the BZs of the system have reached economic equilibrium. This is verified when all PUs left have EBITDA>0. The share of unprofitable capacity removed in an iteration,identified for each BZ as a percentage of the total, is called "nodal step". The following preliminary quantities are computed:

$$Perc\ MM_i = \frac{MMcapacity_i}{InstalledCapacity_i} \tag{5}$$

$$Mean = \frac{\sum Perc\ MM_i}{n} \tag{6}$$

- $MMcapacity_i$: total missing money capacity in the i-th BZ [MW].
- $InstalledCapacity_i$: total capacity installed in the i-th BZ [MW].
- n: number of BZs in the system presenting missing money capacity.

For each BZ the nodal step is computed differently with the following logic:

- $PercMM_i<Mean$:

$$Nodal\ step_i = VarStep + (1 - VarStep) \times Control \times \frac{Mean - Perc\ MM_i}{Mean - \min(Perc\ MM)} \tag{7}$$

- $PercMM_i>Mean$:

$$Nodal\ step_i = VarStep - (1 - VarStep) \times \frac{1+Control}{2} \times \frac{Perc\ MM_i - Mean}{\max(Perc\ MM) - Mean} \tag{8}$$

Terms appearing in the formulas are obtained as follows:

$$VarStep = GlobalStep + \left(\frac{1-GlobalStep}{2}\right) \times Control^2 \tag{9}$$

$$Control = 1 - \frac{MMcapacity_{tot}}{InstalledCapacity_{tot}} \tag{10}$$

- GlobalStep: a parameter of the methodology included between 0 and 1. The closer it is to 1, the faster all PUs became profitable but the further BZs will be from the economic equilibrium.
- MMcapacitytot: total missing money capacity in the system [MW].
- InstalledCapacitytot: total capacity installed in the system [MW].

The percentage of missing money capacity removed from each BZ is composed by the PUs presenting the lowest negative EBITDAu.

C. Converged system configuration

The economic equilibrium of a BZ is reached when all its PUs are profitable in the scenario depicting the TY. The whole iterative process ends when all the BZs of the system reach the equilibrium, and therefore all the PUs left in the perimeter have EBITDAu>0. The final configuration will present a mix of real and standard candidate PUs. The real PUs that have been removed during the analysis represent the existing capacity that is expected to be decommissioned in the TY. The standard candidate PUs which instead survived until the end represents the new entry capacity.

IV. METHODOLOGICAL APPROACH: MULTI-YEAR ANALYSIS

The logic behind the analysis of a multi-year TH is schematically reported in Fig. 2. The decisions taken in each TY consider the performance of PUs also in the following ones, and at the same time will reflect directly on them. In the following the analysis performed for each TY and how it interacts with the others are described in detail.

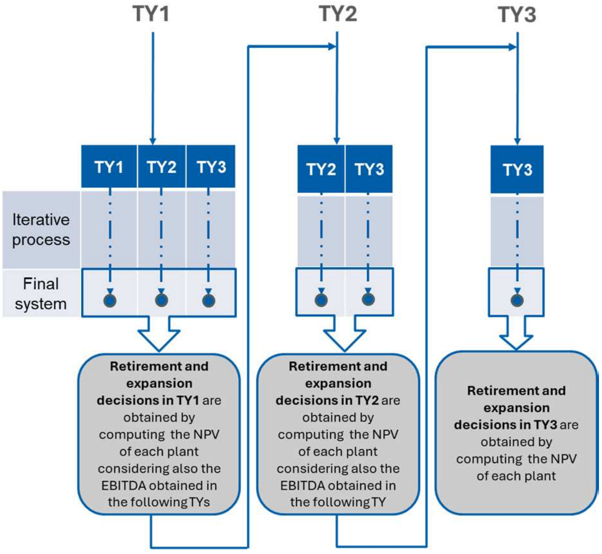

Figure 2. Multi-year analysis development

A. Assessing the single TY

The TH is assessed by analysing chronologically its TYs. The TY currently in the scope is called Main Target Year (MTY). Iterative market simulations are performed simultaneously on the system related to the MTY and on those representing the following TYs. When the system of each TY reaches the economic equilibrium, from each one of them the final EBITDAu related to all PUs in the perimeter is extracted. For those PUs which resulted to be unprofitable, the EBITDAu is considered to be negative and equal in module to their costs as if their production in that TY amounts to 0 MWh. In order to assess the performance of each PU, its Net Present Value (NPV) is computed by actualising the EBITDAu of all analysed TYs to the MTY:

$$NPV = \sum_{i=1}^{n} EBITDA_{uY_i} \times (1 + WACC)^{(MTY - Y_i)} \tag{11}$$

- $EBITDAu_{Y_i}$: unitary EBITDA of the PU related to the i-th TY [€/MW].
- n: number of TY following the MTY.

If there are gap years (GYs) between the TYs which have not been directly analysed, the EBITDAu of a PU related to one of them is obtained through interpolation between the values of the adjacent TYs. Existing units that are expected to be retired in the TYs following the MTY will have EBITDAu = 0 €/MW in these TY while computing the NPV.

B. Moving to the following TY

Given the performance of all PUs in a MTY, decisions are taken to identify the system configuration that will be assessed in the analysis of the following TY. These decisions represent the behaviour of rational investors who identify investment opportunities or decommissioning necessities. The applied logic follows:

- Real PUs with both EBITDAu<0 in the MTY and NPV<0, are considered decommissioned since 01/01/MTY, so they will be removed from the system in the following TY because prove to be economically unviable in the whole remaining TH.
- Standard candidate PUs with both EBITDAu>0 in the MTY and NPV>0 are considered expanded since 01/01/MTY, so they will be part of the system in the following TY and their economic viability will not be assessed anymore. In fact, they prove to be a profitable investment.

In all other cases no decision is taken. These changes affect the perimeter of the analysis that will be considered in the following TY. The analysis of the TH ends when its last TY has been assessed.

V. RESULTS: CASE STUDY ITALY

The presented methodology has been employed in the 2023 version of the Italian National Resource Adequacy Assessments (NRAA)[14].The results it produced show a significant difference in comparison to the Cost Minimisation Approach implemented in the 2023 release of the ERAA[15]. In particular, given an installed thermal capacity of about 53 GW in 2033, the NRAA sees a higher decommissioning. Fig. 3 shows how the Italian NRAA has 19.7 GW of decommissioned thermal capacity in 2033, while the ERAA removes from the system only 17.9 GW.

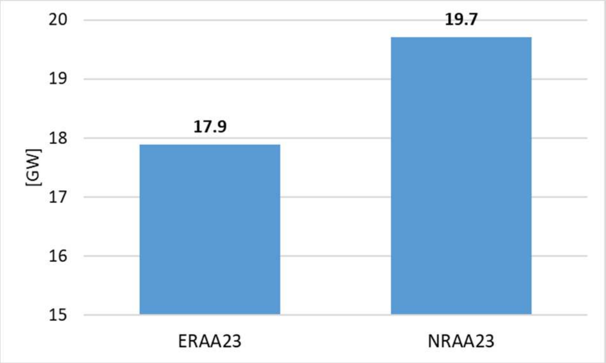

Figure 3. Italian EVA results of the ERAA23 and the NRAA23

The behaviour displayed by the Revenue Based Approach proves how it reproduces a more realistic evolution of the system in comparison to the Cost Based one, which tends to underestimate the decommissioning risk due to various reasons, among which:

1. Unit by unit analysis (NRAA) instead of aggregation of generators in clusters (ERAA);
2. Iterative approach (NRAA) instead of one-shot Central Planner optimization with perfect foresight (ERAA);
3. Comparison of expected producer revenues and costs at the level of individual units (NRAA) instead of total system cost minimization (ERAA).

VI. CONCLUSION

A new approach based on expected producer revenues and costs has been presented. It revolves around an iterative process which aims to identify the economic equilibrium of the system by maximising the revenues of each market player. The main steps of the methodology have been explained in detail highlighting the logic behind them and linking the analysis of a single TY to the one of a multi-year TH. Results have been compared to the numbers returned by the Cost Based Approach showing how the Revenue Based one is more suitable for adequacy studies. Moreover, the detail reached by its outputs makes the new approach extremely versatile. In fact, the PU level detail could be used also by investors to assess the quality of a business plan. The flexibility of the methodology allows to easily introduce supplementary parameters such as new revenue sources or costs to represent particular market conditions. Further studies can be performed to enrich the procedure with new decision options the like of mothballing and life extension. This would lead to an ever more realistic simulation of the future evolution of the power grid.

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