Memo[1]

Risk modelling in adequacy assessments

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1 Introduction – Context and objectives

1.1 A resource adequacy assessment is a forward-looking modelling exercise used to determine whether the resources in an electricity system are adequate to meet the expected demand and guarantee the required reliability standard. Such an adequacy assessment is typically used by Transmission System Operators (TSOs) to determine whether State intervention would be needed to guarantee security of supply (e.g. via introduction of a Capacity Remuneration Mechanism).

1.2 Due to their forward-looking nature, adequacy assessments are subject to several uncertainties on the evolution of the electricity system, regarding both supply and demand, and need to factor in the risks that affect the availability of resources in real time. Those risks and uncertainties – that may be difficult to quantify – need to be adequately accounted for by the TSO for the purpose of conducting the adequacy outlook.

1.3 In particular, it is essential that TSOs form a realistic view of the resources available in the future, considering the likely market developments and economic decisions of operators to invest in/retire plants. TSOs need to consider the risk perception and risk aversion among market operators and investors when modelling market functioning, revenue outlook, the risk profile of investments and their economic viability.

1.4 There is currently no consensual approach to this multifaceted issue in national adequacy assessments. In the context of the development of the European Resource Adequacy Assessment (ERAA) provided by Clean Energy Package,[2] TSOs need to come up with a coherent method for modelling risk and assessing the economic viability of assets. This memo aims to contribute to the discussions on possible evolutions and alignment of the methodology by addressing the following aspects:

- The mapping of the different types of risks and uncertainties, as well as of the typical modelling approaches in adequacy assessments (Section 2);
- The limitations of current approaches in accounting for risks and uncertainties (Section 3);
- A pragmatic way forward is proposed to ensure risks and uncertainties are treated in the most coherent and robust way in the adequacy assessment (Section 4).

2 Risk mapping, modelling and accountability in adequacy assessments

Market operators and investors face various types of risks and uncertainties which are relevant to the adequacy assessment

2.1 Risks and uncertainties[3] affecting market operators and investors are of various kinds corresponding to the main drivers of the profitability of their assets:

a. **Implementation or construction risk**, including delay or budget overrun (for technical, regulatory or administrative reasons, e.g. delay in permitting, connection etc.);

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[2] Article 23 of the Electricity Regulation of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity.

[3] Note that further distinction between measurable risk and ‘true’ uncertainty is made in paragraph 3.3.

b. **Operation risk** resulting in asset unavailability, due to planned or unplanned outage for technical or social reasons (i.e. strikes), unfavourable climate conditions for renewable energy sources (RES) or even thermal plants (water temperature for reactors cooling, river level for coal shipping etc.);

c. **Market risks** resulting in low market prices or profit margins. These can affect either the demand side (e.g. reduced consumption due to an economic crisis) or the supply side with some cannibalisation risk (i.e. addition of more efficient units or technologies). They also include commodity price risks (inflation of gas, coal or carbon prices, squeezing profit margins);

d. **Policy or regulatory risks**, such as a nuclear or coal phase-out, RES or premature support abatement for demand-side response (DSR), the introduction of caps on operating hours or carbon emissions or other environmental regulations (e.g. directives on air pollutants), the revision of the rules of the carbon market – or the introduction of a carbon price floor – of the capacity market, including regarding eligibility or derating (e.g. for energy-constrained capacity like DSR or storage), or of the energy market (e.g. price cap revision), etc.

2.2 These various risks and uncertainties can be classified in two categories based on when they are likely to materialise. That is:

a. **'Long-term' uncertainties** in the evolution of the macroeconomic and electricity system context. These pertain to the structural developments of the market and regulatory frameworks, geopolitical context, innovations affecting the evolution of demand, the development of RES, storage, fossil-fuel and carbon prices, etc.

b. **'Short-term' uncertainties** regarding primarily weather conditions and availability of assets. In practice, these are uncertainties in terms of electricity demand, RES generation and availability of thermal, nuclear energy sources and HVDC interconnectors.

An explicit 'exogenous' approach typically combines with an implicit 'endogenous' approach to factor in these risks and uncertainties in adequacy assessments

Explicit 'exogenous' approach – definition of differentiated scenarios and sensitivity analyses to factor in long-term uncertainties, and simulation of operational or climate hazard in the short term (Monte Carlo simulation)

Principle

2.3 In order to explicitly factor in long-term uncertainties, TSOs typically build various long-term scenarios and conduct sensitivity analyses that may differ in terms of demand trends, development of the installed capacity in RES, DSR, thermal power plants or interconnectors, expected availability of these assets, or regarding the long-term trends in fuel and carbon prices.

2.4 Besides, simulations of hazard account for more short-term operational risks that may prevent some resources from being available. A probabilistic approach using Monte Carlo simulation is recommended as best practice and this is now usually applied in adequacy assessments.

Practical implementation

2.5 Uncertainties can typically be represented in the form of a “hazard tree” to account for increasing uncertainty the further the time horizon extends (e.g. uncertainties for 2020 are lower than for 2030). Each node of this hazard tree represents a possible future and each branch of the tree is associated with a possibility of change in the energy context. Moreover, different scenarios and short-term variables are associated with each node of the hazard tree (e.g. weather variables). This hazard tree enables simulation of decision-making (on investments, mothballing, closure or maintenance in service) under conditions of uncertainty.

2.6 In practice, in the adequacy assessment, TSOs limit the number of scenarios, sensitivity analyses and variables in Monte Carlo simulations to a reasonable and computable number, while trying to capture the effects of key risks and uncertainties on adequacy and their correlation, in order to reach enough confidence or convergence on the results.

2.7 This approach indicates the level of capacity necessary to procure to meet the LOLE[4] Reliability Standard. However, this approach disregards the economic profitability of this capacity. An implicit approach based on ‘endogenous’ economic viability can be used to complement it (see next sub-section).

Implicit approach – endogenous modelling of the economic viability of the assets based on an economic viability criterion and on a discount rate accounting for the ‘financial’ risk

Principle

2.8 Rather than exogenously determining the merchant capacity (i.e. CCGT, OCGT, storage, DSR etc.) added to or withdrawn from the market, their viability can be based on their expected return distribution and profitability as a model output (‘endogenous’ modelling).

2.9 The economic assessment allows assessment of whether the Reliability Standard can be reached without state intervention, relying on the anticipated market revenues of power. This is an essential feature in the analysis and comparison of the potential market designs for the electricity sector (Energy-only market, capacity market etc.).

2.10 The investment dynamics depend on the expected revenues as well as on the level of risk perceived by market players and their behaviour in the face of this risk. Capacity operators and investors bear a financial risk regarding the economic profitability of their assets because, among other things, of the existence of uncertainties on the levels of energy and capacity revenues and their fluctuation.

2.11 Considering the risk leads to adjusting the financing cost. The higher the risk regarding the project profitability, the higher the expected return investors require. This expected return threshold is often measured by the weighted average cost of capital (WACC) which correspond to the weighted average return fund providers/investors of the project expect. Weights correspond to the share of funds provided by each category of investors.

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[4] Loss of load expectation.

Practical implementation

2.12 In practice, to determine whether any merchant capacity is added or withdrawn in the market, the adequacy study includes an 'economic viability test' based on a criterion to be determined, such as the net present value (NPV) of its expected cash flows (i.e. revenues and costs) discounted at the cost of capital (i.e. required return or discount rate). This 'economic viability test' typically follows an iterative process.[5]

2.13 The effect of the return distribution[6] on the cost of capital can be represented using a utility function[7] which tends to penalise decisions that result in uncertain revenue. Various types of utility functions[8] and risk aversion models can be employed.

2.14 The capital asset pricing model (CAPM) is the most widely used model for estimating the cost of financing a project with equity. The CAPM determines an expected return based on several assumptions:[9]

- CAPM assumes a particular form of utility functions in which only the first and second moments of the return matter (that is risk is measured by variance) or, alternatively, asset returns whose probability distributions are completely described by the first two moments (the normal distribution);
- The model only considers the asset's sensitivity to non-diversifiable risk (also known as systematic risk or market risk) as opposed to diversifiable risks that can be eliminated through portfolio diversification;
- The model assumes perfect information and zero transaction costs (necessary for diversification to get rid of all diversifiable risk).

2.15 There is currently no consensual WACC approach in adequacy assessments:

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[5] To determine the capacity mix at the equilibrium, several iterations are performed to converge toward a capacity mix in which the generators and DSR operators have positive NPV, based on the avoidable costs and the market revenues, and where no additional investment would have a positive NPV.

[6] The distribution of returns can be simulated using the probabilistic Monte Carlo approach described above, simulating yearly revenues according to several hundreds of different generation patterns of renewables (over different climate years) and forced outages.

[7] In economics, a utility function is a representation to define individual preferences for goods or services beyond the explicit monetary value of those goods or services.

[8] Economic publications suggest different utility functions to represent risk aversion. In particular, there are two classic types of utility function: i) the CARA (constant absolute risk aversion) function, which assumes that the absolute risk aversion level does not increase with the initial wealth of the agents, and ii) the CRRA (constant relative risk aversion) function, which, on the contrary, assumes that the absolute risk aversion level varies with the initial wealth of the agents. These utility functions were historically proposed and discussed by Arrow (1965, 1970) and Pratt (1964). Arrow, K. J., Aspects of the theory of risk-bearing. Yrjö Jahnssonin Säätiö. 1965. Arrow, K. J., Essays in the theory of risk-bearing. Amsterdam, London: North-Holland. 1970. Pratt, J. W., Risk aversion in the small and in the large. Econometrica: Journal of the Econometric Society, 1964. pages 122-136.

[9] Eugene F. Fama and Kenneth R. French (2004). *The Capital Asset Pricing Model: Theory and Evidence.* Journal of Economic Perspectives, 18 (3): 25-46.

- WACC can be determined either exogenously (via an independent study/benchmark) or endogenously to the adequacy study (e.g. risk and WACC premium assigned to investors computed based on the modelled revenue fluctuation), or with a hybrid approach combining both a base WACC determined exogenously with WACC premia determined endogenously;[10]
- WACC can be either asset-specific or normative, i.e. for a technology class (e.g. CCGT, OCGT etc.) and/or market operator type (Utility, IPP etc.).

3 Limitations of the typical risk modelling approaches

The limitations of explicit risk modelling using scenarios and Monte Carlo simulations: they account for some measurable risk while tending to ignore 'true' uncertainty

The limited number scenarios and variables in the Monte Carlo simulations limits the scope of risks that can be apprehended

3.1 In practice, the TSO is unable to estimate the capacity revenue for all possible scenarios. Using a limited number of scenarios and variables in the Monte Carlo simulations is needed to control the size of the hazard tree considered, but it tends to limit the scope of risks that can be apprehended in the Adequacy assessment.

3.2 Besides, information regarding the modelled events, their probability of occurrence and correlation is limited, in particular related to extreme events (See 3.4 to 3.6 below). This results in some residual uncertainty not being adequately captured (so-called 'true uncertainty' – see below).

Contrary to measurable risk, 'true' uncertainty cannot be modelled

3.3 Distinction between measurable risk and true uncertainty was formalized by Frank Knight in 1921.[11] According to Knight, risk applies to situations where we do not know the outcome of a given situation, but can accurately measure the odds. Uncertainty, on the other hand, applies to situations where we cannot know all the information we need in order to set accurate odds in the first place. *"There is a fundamental distinction between the reward for taking a known risk and that for assuming a risk whose value itself is not known,"* Knight wrote. A known risk is *"easily converted into an effective certainty,"* while *"true uncertainty,"* as Knight called it, is *"not susceptible to measurement."*

True uncertainty particularly affects the most extreme events making it impossible to adequately assess realistic probabilities of occurrence

3.4 In the electricity markets, the occurrence of very rare price spikes depends to a large extent on a high number of unknown 'extreme' events that can hardly be predicted (including political interventions, modification of the legal or regulatory framework at the national or European level, etc.).

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[10] See for instance RTE (2018). *Impact assessment of the French Capacity market*

[11] Knight, F. H. (1921) *Risk, Uncertainty, and Profit.*

3.5 Their modelling is often based on past events (historical data series) that can be adjusted to be considered representative, but that may not perfectly reflect future trends and probability due to possible statistical bias on past data or fast-changing environments (such as unpredictable climate conditions in the medium to long term[12], abrupt evolution of the policy or regulatory framework, unexpected technological breakthroughs etc.).

3.6 The Extreme Value Analysis (EVA) theory[13] that seeks to better assess the probability and weights of events that are more extreme than any previously observed remains theoretical and difficult to apply in practice, in particular for investors or the TSO in the adequacy assessment.

The limitations of implicit 'financial' risk modelling based on an economic viability criterion and discount rate

3.7 The first limitation of the traditional approach to discounting cash flows is that WACC is conventionally calculated and then applied to all future cash flows, even though the appropriate discount rate and cost of capital for a particular year depends on parameters that are not constant over time (price of risk, beta,[14] leverage).

3.8 Besides, 'financial' risk modelling is based on the definition of a utility function and risk aversion model that rely on strong assumptions and a limited number of parameters. As an example, we provide below a critical review of the CAPM.

The CAPM assumes normal distribution of returns and disregards important distribution features

3.9 As previously mentioned, the CAPM only considers the return variance and adequately accounts for normal probability distributions. As such, CAPM WACC premia calculated based on return variance disregard the skewness, kurtosis and large tails of the distribution that may pose additional risks to investors.

3.10 In particular, the assumption of normal distribution hardly holds for the returns earned in the power market, where prices and inframarginal rent can be very volatile and result in highly skewed return distribution with outliers.

Diversifiable and non-diversifiable risks are often hard to distinguish in practice, making it hard to eliminate all diversifiable risk

3.11 In addition, as previously mentioned, the CAPM assumes perfect rationality and information of parties regarding risk, and zero transaction costs (necessary for diversification to get rid of all diversifiable risk).

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[12] For instance, the current MAF methodology adjusts historical weather data in order to account for the expected impact of climate change, but the occurrence of some extreme weather events may not be represented in the historical data and therefore may remain hard to predict (neither can they be in simulated future weather time series from meteorological models).

[13] Hull, J. 2015 *Risk management and financial institutions*, Part II, Chapter 13 (p277)

[14] The beta (β or beta coefficient) of an investment is a measure of non-diversifiable risk, i.e. the risk arising from exposure to general market movements as opposed to diversifiable risk factors.

3.12 However, in practice diversifiable and non-diversifiable risks may be hard to distinguish for market operators and, due to imperfect capital markets, risk diversification strategies are subject to some limitations. Hence, in addition to non-diversifiable risks, investors may carry residual theoretically diversifiable risks (not accounted for by the CAPM model).

Risk perception depends on the market context and on the view of each investor – it is highly subjective

The Energy Market imperfections exacerbate the uncertainty

3.13 The power market paradigm relies on the ability of market players to gain revenues from price spikes occurring during scarcity events, and assumes that necessary hedging strategies and products would be developed to make the revenue streams from the price spikes more reliable. In theory, opposite risks may thus be neutralized through exchange of products for hedging price spikes (forward products, options, etc.) or vertical integration ("upstream-downstream") of companies through generation and supply activities.

3.14 However, these hedging opportunities (that could mitigate return volatility and reduce WACC) remain limited in the long term:

- In practice, it is uncertain to what extent price spikes are adequately reflected in the forward prices.[15] Besides, there are currently no liquid forward products beyond a three-year horizon that corresponds to the term of supply contracts (suppliers seek to cover risk related to sourcing of their customer portfolio). But this may improve with the development of corporate PPAs and long-term forward products;
- The effect of vertical integration could reduce short-term risks, but not long-term ones, as imbalances between the upstream and downstream portfolios of utilities can increase.

The local context may further contribute to the market imperfections and increase the risks for investors

3.15 Relatively small and highly interconnected countries are not only directly affected not only by national decisions and events, but also by political decisions or operational contingencies in neighbouring countries. A recent example is the systemic defects identified in the French nuclear fleet, which created power price spikes in the Belgian market.

The adequacy study is conducted from the TSO point of view and cannot model all events and cover all the risks facing each investor

3.16 The perception of risk by investors and its impact on the actual decisions may diverge from the TSO model. In their internal projections, the market players and investors providing funding

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[15] Bessembinder and Lemmon first introduced a theoretical framework that lays the foundations for a possible link between spot and forward prices (Bessembinder H., Lemmon M.L. (2002). *Equilibrium pricing and optimal hedging in electricity forward markets.* The Journal of Finance 57(3) pp. 1347–1382.). This theoretical link has been tested on various market contexts, and has largely not been validated by subsequent empirical analyses, as it depends on several strong assumptions that are often not verified. See for instance Botterud A., Kristiansen T., Ilic M. (2009). *The relationship between spot and futures prices in the Nord Pool electricity market.* Energy Economics, Volume 32, Issue 5. and Redl C., Haas R., Huber C., Böhmer B. (2009). *Price formation in electricity forward markets and the relevance of systematic forecast errors.* Energy Economics 31,356–364.

are likely to adjust the weights and probabilities differently, exclude the more extreme favourable scenarios (e.g. very high price spikes) as too optimistic, or consider different scenarios. In particular, the market players and investors may want to explicitly model some additional construction, operation, market or regulatory risk that the project may be particularly sensitive to, and that the adequacy assessment may not necessarily capture.

3.17 That is why in practice, the perception of costs, revenues and risks by investors, and its impact on actual investment decisions, may diverge from the TSO's view. Hence, when making investment decisions, a risk-averse investor may adopt a prudent approach with respect to the profitability assessment provided in the adequacy study.

4 Conclusion – Pragmatic ways forward to ensure that risks and uncertainties are treated in the most coherent and robust way

4.1 In adequacy assessments to date, there is no established or consensual practice regarding the multifaceted issue of risk modelling, with the current approaches showing significant limitations.

4.2 We therefore recommend that the interested parties work together at the European level to develop a coordinated set of best practices and approaches and improve alignment between the risk modelling and the actual investment decision criteria.

4.3 Using as a starting point the standard discounted cash flow (DCF) approach with a discount rate derived from the CAPM, we see several ways of amending this standard approach so as to take into account risk aversion, market imperfection or the shape of the cash-flow distribution.

4.4 First, one could adjust the cost of equity so as to take into account the impossibility for some market participant to obtain a well-diversified portfolio. Building upon the CAPM, Damodaran (2011) proposes replacing the standard beta by a "total beta" in the case of a completely undiversified investor. The total beta corresponds to the standard beta divided by the coefficient of correlation between the stock return and the market index return.[16] Such an approach provides room to consider the case of investors with imperfect possibility of diversification.

4.5 Second, utility functions used for the purpose of economic modelling are most of the time assumed to be "smooth" (i.e., twice continuously differentiable) and concave. However, beyond risk aversion, which can be observed for any level of wealth, investors may also exhibit loss aversion which may add kinks or discontinuities to a utility function.[17] This may lead to investment decision rules more complex than the binary textbook rule "invest if NPV is positive and do not invest if NPV is negative". Such an approach could be extended to take into account

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[16] Damodaran, A., 2011, Applied Corporate Finance, 3rd edition, Wiley.

[17] See, Kanheman, D. and A. Tversky, 1992, Advances in prospect theory: Cumulative representation of uncertainty, Journal of Risk and Uncertainty, 5: 297-323. They estimate the parameters for a utility function of the shape $U(x)=x^a$ if $x \geq 0$, and $U(x)=-k(-x)^b$, if $x<0$. They find that $a=b$ and $k>2$.

other risks metrics such as Value at Risk (VaR),[18] Expected Shortfall (ES),[19] or alternative economic viability criteria based on a median return.

4.6 Third, it is well known that if instantaneous returns are normal, then the price process is lognormal and, unless the measurement interval is very small, returns are not normally distributed[20]. This leads, among other things, to considering third moments of the distribution of returns, i.e., skewness. Everything else being equal, investors should prefer portfolios that are right-skewed to portfolios that are left-skewed. Consequently, assets that make the portfolio returns more left-skewed are less desirable and should command higher expected returns. Similarly, assets that make the portfolio return more right-skewed should have lower expected returns. This lead to a modified CAPM where the excess expected return of an asset is a linear function of market risk premium, and the square of the market risk premium and coefficient of the risk premia are function of the skewness of the market return distribution.[21]

4.7 Further research would be needed to develop these alternative or complementary approaches and determine whether are economically sound, robust and simple enough to implement and calibrate in practice. Should various methods and risk metrics be jointly applied, it is essential to ensure that they remain coherent with all relevant risks and uncertainties adequately captured, either explicitly or implicitly. However, given the various uncertainties regarding investors' risk perception and accountability, including the unmeasurable residual uncertainty, a reasonably conservative approach may be adopted in adequacy studies.

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[18] Value at risk (VaR) is a measure of the risk of loss for investments. It estimates how much a set of investments might lose (with a given probability), given normal market conditions, in a set time period such as a day. VaR is typically used by firms and regulators in the financial industry to gauge the amount of assets needed to cover possible losses. For a given portfolio, time horizon, and probability p, the p VaR can be defined informally as the maximum possible loss during that time after we exclude all worse outcomes whose combined probability is at most p.

[19] Expected shortfall (ES) is another risk measure to evaluate the market risk or credit risk of a portfolio. The "expected shortfall at q% level" is the expected return on the portfolio in the worst q% of cases. ES is an alternative to value at risk to better account for the shape of the tail of the loss distribution.

[20] See, for example, Merton, R., 1982, On the mathematics and economics assumptions of continuous-time models, in William F. Sharpe and Cathryn M. Cootner, eds.: Financial Economics: Essays in honor of Paul Cootner, Prentice-Hall.

[21] See for instance Harvey, C.R., & Siddique, A. (2000). *Conditional Skewness in Asset Pricing Tests.* Journal of Finance 55, no. 3 (June 2000), pp. 1263–1295.