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RELIABILITY OPTIONS: REGULATORY RECOMMENDATIONS FOR THE NEXT GENERATION OF CAPACITY REMUNERATION MECHANISMS

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Abstract

The policy and regulatory debate raised after the 2022 energy crisis has reaffirmed capacity remuneration mechanisms (CRMs) as a key element of the electricity market design required to drive the much-needed energy transition. Reliability options are a CRM product that effectively addresses the market failures impacting security of supply, while minimising the interference with the different segments of the energy market. This article provides a comprehensive and detailed assessment of the design elements of reliability options and advances recommendations that can be useful for regulators who may consider introducing this scheme in their electricity markets. The analysis benefits from lessons learned in those power sectors where reliability options have been implemented (Colombia, ISO New England, Ireland, Italy, and Belgium). This allows to narrow the gap between the theoretical debate and the real-world implementation of these mechanisms.

Keywords

Reliability options; Capacity mechanisms; Capacity markets; Resource Adequacy; Strike price; Financial hedge.

1 INTRODUCTION

Capacity Remuneration Mechanisms (CRMs) are meant to enhance resource adequacy, an increasingly challenging task as power systems transition towards low-carbon technologies. The key aim is to attract the resources needed to achieve an adequate expansion of the power system, complementing the economic signals conveyed by the energy market with more stable and predictable revenues (Keppler, 2017). These regulatory instruments have historically been ostracised by European institutions, since they are viewed as obstacles to market integration and as potential tools that Member States may use to pursue energy autarchy (Hancher et al., 2019). CRMs have also been accused to unnecessarily subsidise fossil-fuel-driven generation (Komorowska et al., 2023), whose market share is affected by the fast-paced renewable penetration. In recent years, however, CRMs have also played a key role in fostering the development of new business models, such as demand response or storage (Fraunholz et al., 2021), and they are open to renewable participation, although with mixed results, (Kozlova et al., 2023). Furthermore, at least in the European Union after the publication of the Clean Energy Package in 2019, they are subject to strict emission limits that must be met by the supported resources. In the last decade, CRMs have been gradually introduced by more than ten European Member States, including all major economies, and they have registered a dramatic growth in their budget[1], as shown in Figure 1.

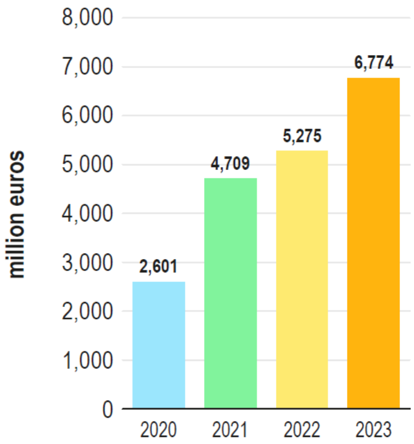

Figure 1. Costs incurred or projected to finance CRMs in EU-27 (ACER, 2022a)

Several experts and regulators highlighted how the role of capacity mechanisms is envisioned to grow during the energy transition (BEIS, 2022). CRMs have also been mentioned as part of the solution to the energy crisis that the European Union suffered since 2022. For example, Meeus et al. (2022) call for these mechanisms to be included in the target model (instead of being treated as temporary solutions to specific or isolated adequacy concerns), as a first step to harmonise them at the regional level. A first step in this direction was recently made by the European Council (2023), which agreed remove the temporary nature of CRMs.

Reliability options (ROs) are a product that can be traded in capacity mechanisms. They cover demand with a physical call option to be activated during scarcity conditions, reflected

[1] It must be remarked that the budget devoted to the CRM is not a simple addition to the cost of electricity supply, since its introduction alters other supply costs, especially those related to non-served energy.

by abnormally high prices. ROs present several advantages if compared with other reliability products, especially in terms of low interference with the energy market. This is due to the fact that its activation is based on a reference market price and that such activation only takes place in extreme circumstances (Cramton and Stoft, 2005).

Recognising these benefits, Pototschnig et al. (2022) highlight that, out of all potential reliability products, ROs best fits the principles of the European legislation regarding the Internal Energy Market and propose them as a possible reference for CRMs in Europe. This opinion seems to be supported also by a regulatory trend in European CRMs, with schemes based on reliability options being introduced in Ireland (EC, 2017), Italy (EC, 2018), and Belgium (EC, 2021). Beyond Europe, ROs have been originally designed for the Colombian power market (CREG, 2006) and a variation of this product was introduced also in the capacity market of ISO New England (Potomac Economics, 2009).

Reliability options, however, is a label that can encompass a variety of different designs (Table i) and hide a significant complexity. ROs must be tailored to both the characteristics of the power system and the primary (and secondary) motivations behind their introduction. The goal of the article is to delve into these details, providing a comprehensive and up-to-date assessment of the design elements of reliability options, identifying the alternatives for each of them, and drawing regulatory recommendations that can help improve the economic efficiency of capacity mechanisms based on ROs. The assessment presented in this article draws on the real-world implementation of ROs. Each design element is first assessed from a theoretical point of view, but then the real problems and discussions encountered by regulators who introduced reliability options in their systems are also studied, in order to understand why different systems opted for different designs. The design elements that have been reviewed are summarised in Table i, together with the main design alternatives that will be analysed in the body of this article. Other aspects of CRM design that go beyond the reliability product are not assessed in this article.

Table i. Summary of RO design elements

<table>
<tr><td rowspan="2">Reference market for the financial settlement (section 3.1)</td><td colspan="4">Single reference market</td><td colspan="2" rowspan="2">Multiple reference markets</td></tr>
<tr><td>Day-ahead</td><td colspan="2">Intraday</td><td>Balancing</td></tr>
<tr><td>Penalties for underperformance (section 3.2)</td><td colspan="4">Explicit penalty</td><td colspan="2">Option settlement with Administrative Scarcity Pricing</td></tr>
<tr><td>Stop-loss mechanism (section 3.2)</td><td colspan="4">Limit based on CRM remuneration</td><td colspan="2">Limit based on CONE</td></tr>
<tr><td>Capacity commitment (section 3.3)</td><td colspan="4">Fixed obligation</td><td colspan="2">Load-following obligation</td></tr>
<tr><td rowspan="2">Strike price (section 3.4)</td><td colspan="4">Unique strike price</td><td colspan="2">Multiple strike prices</td></tr>
<tr><td colspan="4">Based on the variable costs of a proxy unit</td><td colspan="2">Based on historical prices</td></tr>
<tr><td>Indexation (section 3.4)</td><td colspan="2">Variables in the formula</td><td colspan="3">Frequency of updates</td><td>Ex-ante/ex-post</td></tr>
<tr><td>Hedge for consumers (section 3.5)</td><td colspan="4">Direct</td><td colspan="2">Indirect (lower CRM charges)</td></tr>
<tr><td>Interactions with long-term contracts (section 3.6)</td><td colspan="4">Harmonised settlement</td><td colspan="2">Separated settlement</td></tr>
</table>

Some of the discussions presented in the article have already been analysed in literature (e.g., how to define the RO strike price; Vázquez et al., 2002; Cramton and Stoft, 2005, 2008; Bidwell, 2005) and here they are summarised and assessed through the review of international experiences. Other discussions, as the details of the penalty scheme, the kind of hedge for consumers, or the possibility of load-following obligations, at the best of the authors' knowledge, have not been addressed in the academic literature and are thoroughly analysed here, together with their implications for the efficiency of the CRM.

The article is structured as follows. Section 2 provides the background on reliability options, their role as a product in a CRM rather than a CRM design itself, and summarises their advantages compared to other products. Section 3 presents the assessment of all the design elements of reliability options, listing alternative approaches from theory and international experiences. Section 4 draws regulatory recommendations to improve the design of reliability options, before some concluding remarks are presented in section 5.

2 RELIABILITY OPTIONS: A RESILIENT PRODUCT FOR CRMS

Capacity mechanisms complement the short-term electricity market with a long-term signal meant to guarantee resource adequacy in the power system. Their need (Joskow, 2008; Milstein and Tishler, 2012), their impact on the social welfare (De Vries and Heijnen, 2008; Cepeda and Finon, 2011; Milstein and Tishler, 2019), and their design (Cramton et al., 2013) have been extensively evaluated in the academic literature over the last two decades. Different CRM designs are possible (capacity auctions, strategic reserves, etc.). Finon and Pignon (2008), EC (2016), and Bublitz et al. (2019) presented a thorough comparison of these different approaches.

ROs are a type of reliability product that can be traded in a capacity market. They were first proposed by Vázquez et al. (2002), in the framework of the process for reforming the capacity payments implemented at the time in Colombia. They were further developed by Cramton and Stoft (2005, 2008), who worked on their implementation in Colombia and ISO New England. ROs have been analysed in several articles in the academic literature (Woodhouse, 2016; Bhagwat and Meeus, 2019; Andreis et al., 2020).

According to the original design, the product consists of a physical call option, whose seller commits to deliver its supply whenever the price in a reference market exceeds a certain strike price (a threshold that signals scarcity conditions) and to return the difference between the market price and the strike to the buyer (financial settlement of the call option). If the seller is not able to produce during scarcity conditions and, therefore, does not have access to the market price, it will have to return such difference anyway and will also be subject to an explicit penalty for non-delivery (this is the physical component of the product; Batlle et al., 2007). Figure 2 illustrates a basic settlement of a reliability option.

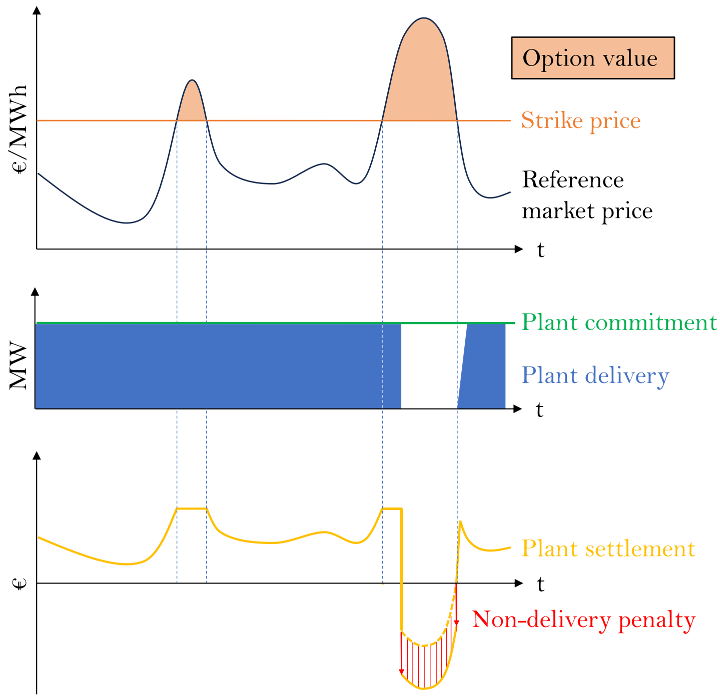

Figure 2. Illustrative example of the settlement of a reliability option

2.1 Tackling market failures while minimising intervention

Reliability options are the CRM product that creates the least distortion in the electricity market while addressing the two main market failures that stand behind the security-of-supply problem (Rodilla and Batlle, 2012; Newbery, 2016).

- The lack of price signals in the short-term market that reflect the utility function of demand during scarcity conditions[2] and allow market agents to recover their investment costs through price spikes. A CRM based on reliability options can include different kind of penalties (see section 3.2) that provide the missing price signal, for committed resources to have a stronger incentive to be available during scarcity conditions. At the same time, committed resources can internalise in their bid these penalties together with the investment cost they do not expect to recover in the energy market, thus solving the so-called missing-money problem.
- The lack of a liquid long-term market where demand and supply can hedge their complementary risks. The call option is a long-term contract that covers demand from price spikes. Committed resources renounce to the revenues from these price spikes in

[2] The maximum price limit applied in the European electricity market is very far from the Values of Lost Load computed for European countries, which could reach 68 887 €/MWh in some Member States (ACER, 2022a).

exchange for a stable premium that helps them hedge their risk. However, if the strike price is properly defined (see section 3.4), this long-term contract covers only a reduced share of future energy trades, leaving enough room for the short-term market to operate efficiently.

2.2 Reliability option: a CRM product not a CRM label

Most of taxonomies of capacity mechanisms used to date (e.g., ACER, 2013) present reliability options as one of the labels of possible CRM designs. However, it must be underlined that ROs are just a reliability product[3] and the latter is only one of the several design elements of a CRM (Batlle et al., 2022a). For instance: i) ROs could be either procured in a centralised auction or traded in a decentralised market (Woodhouse, 2016); ii) they could cover the whole-system demand or only certain consumer groups or iii) resources may be subject to a de-rating process to determine their firm supply[4]. These examples show that there are several decisions that a regulator should take beyond the choice of ROs as the reliability product in order to get to the final CRM design.

2.3 Interference with the energy market

ROs present several advantages compared to other reliability products. Most of these advantages stem from the use of the market price as an indicator of scarcity conditions in the system, as well as a trigger for the activation of the reliability product. This feature allows to minimise the interference of the capacity mechanism with the energy market, a key element for all CRM designs. If the strike price of the option is high enough (and properly indexed), the energy market will clear normally in ordinary conditions and the activation of the capacity mechanism will be limited to those hours in which the system is

[3] Other reliability products commonly traded in capacity markets are, for instance, capacity contracts that require committed resources to deliver their firm supply when the system operator calls for it, based on some technical parameter of the system. These capacity contracts do not have an associated financial contract and are commonly based on a fixed remuneration and a penalty for underperformance.

[4] De-rating factors (also known as capacity credits in the United States) are applied to the installed capacity of a resource willing to participate in a CRM in order to compute its firm supply. The latter represents the amount of reliability product that the resource can sell in the capacity market and commits to deliver during scarcity conditions. De-rating factors should reflect the expected contribution of the resource to the reliability of the system. De-rating methodologies exceeds the scope of this article. See Brito-Pereira et al. (2022) and ESIG (2023) for details.

actually under stress. It must be remarked that the strike price does not act as a price cap in the energy market, since there are resources that do not sign ROs or are only partially covered by them and would still bid above the strike price, if their activation costs are higher.

2.4 Resiliency to increasing demand elasticity

Furthermore, the use of the market price as a shortage indicator is also resilient to the expected increase in the elasticity of electricity demand. When consumers in the system respond elastically to prices, the difference between a period with non-served energy and a period with a very high price becomes blurred[5]. In this context, the adequacy of the system is better measured by the amount of energy supplied beyond a certain price threshold and ROs are a reliability product aligned with this market principle.

2.5 Efficient cross-border participation

Another potential advantage of ROs is that they allow a more efficient participation of cross-border resources in the CRM. This issue is very relevant for regional electricity markets, as the European one. Reliability options are activated by market prices, which also drive the flow through the interconnections between power systems. If scarcity conditions are triggered in a power system with an RO mechanism, it means that the market price exceeded the strike price threshold, i.e., it is higher than in normal circumstances. This should drive net imports from neighbouring systems. Cross-border resources that sold ROs to the former system would then be able to contribute to its reliability, fulfilling their commitment[6].This property is not found in CRMs whose reliability product is activated based on technical parameters of the power system, which are not always fully correlated to market prices. These CRMs may require the contribution from cross-border resources at a time when the regional market prices force a different flow through the interconnections.

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[5] Actually, in a system with a fully-elastic electricity demand, it becomes impossible to define non-served energy or a loss-of-load event (Brito-Pereira et al., 2022).

[6] The situation may become more complex in case of regional scarcity conditions that affect more than one power system. In this case, even with an RO design, it may be necessary to introduce some sort of conditional nomination that allows electricity to flow in the direction of the power system who paid for it through a CRM, as proposed by Mastropietro et al. (2015).

3 THE DESIGN ELEMENTS OF RELIABILITY OPTIONS

When implementing reliability options in a power system, the regulator has to take a few fundamental design decisions, which are becoming even more critical due to the decarbonisation process. The main ones regard the reference market for the settlement of the option, the penalty scheme to foster the performance of committed resources, and the methodology to compute and update the strike price. These decisions give rise to a broad variety of RO designs, which may have very different implications for the resources offering the service and the demand to be covered by the CRM. This section analyses these fundamental design elements of an RO mechanism. As already mentioned, the assessment is not just theoretical, but supported by an in-depth review of the experiences of the five power systems where reliability options were introduced at some stage: Colombia, ISO New England, Ireland, Italy, and Belgium. Table ii summarises these five experiences using the same design elements as in Table i, so that the reader can compare the different approaches at a glance.

Table ii. Summary of RO design in the five power systems under study

Design element	Colombia	ISO New England	Ireland	Italy	Belgium
Reference market for financial settlement	Day-ahead market	Real-time market	Multiple reference markets	Multiple reference markets	Day-ahead market
Penalties for underperformance	No penalty	Explicit penalty	Administrative Scarcity Pricing	Administrative Option Settlement	Explicit penalties
Capacity commitment	Load-following	-	Load-following	Load-following	Fixed obligation
Strike price	Variable costs of proxy unit (fuel oil)	Variable costs of proxy unit (fuel or gas)	Variable costs of proxy unit (fuel/gas/DR)	Variable costs of proxy unit	Historical prices
Hedge for consumers	Direct	Indirect	Direct	Indirect	Indirect
Interactions with long-term contracts	Harmonised settlement	Separated settlement	Separated settlement	Separated settlement	Separated settlement

Before presenting the assessment, a terminological note is required. The elements that characterise the settlement of a reliability option have received very different definitions in the power systems where ROs have been introduced and there is no official or widespread nomenclature in the academic literature. In this paper, we will use the following terms.

- Option premium, which is the fixed annual or monthly amount being paid to the resource for providing the service (i.e., for selling an RO); this is usually determined through a competitive process.
- Option settlement, the RO intrinsic value, which is the difference between the reference market price and the strike price of the option that the resource has to return to the RO counterparty. This cash flow has been also referred to as difference payment (Ireland), payback obligation (Belgium), peak energy rents (ISO New England), or variable compensation (Italy). The option settlement can be "covered", when the resource is producing and is selling energy at the market price, or "uncovered", when the resource has to return the difference between the market price and the strike even if it is not receiving the market price.
- Explicit penalty, which could be included in the RO design to reinforce the signal of the option settlement, and which applies some sort of sanction when the resource is not delivering its full commitment when the reference market price exceeds the strike price.

3.1 Reference market for the financial settlement

A reliability option is activated when the market price exceeds the strike price of the call option. However, modern power systems rely on a variety of market segments, resulting in different prices, which range from the long term to the real-time operation (e.g., day-ahead, intraday, balancing or real-time market). The design of the RO must specify which prices of these market segments will be considered as a reference for the settlement of the option. In theory, this decision mainly depends on the kind of scarcity conditions that are expected in the system in the future, during the operation of the CRM, as represented in Figure 3.

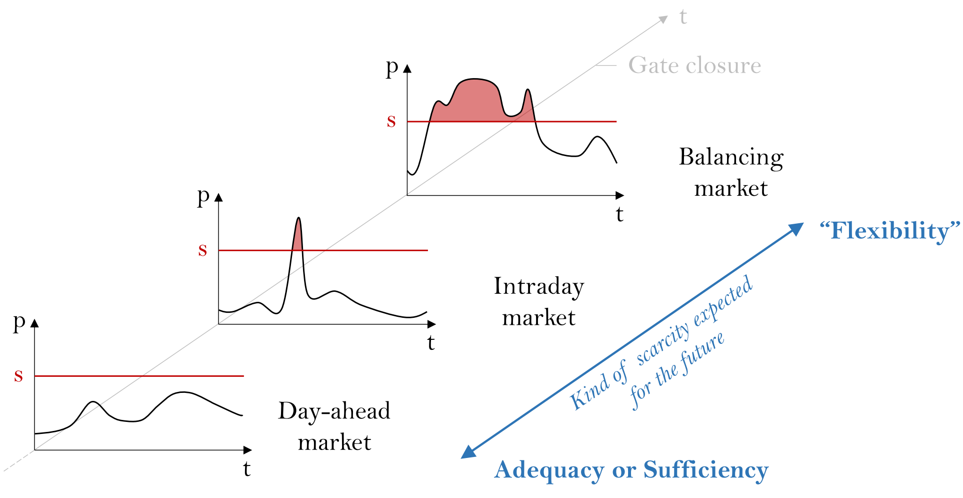

Figure 3. Different alternatives for the RO reference market

From the regulator's perspective, the reference market should ideally be the market segment that is best suited to signal these shortage events. A system whose adequacy concerns are related to a lack of sufficient capacity to cover peak demand during part of the year may opt for the day-ahead market, which is likely to efficiently reflect these stress events. This design was introduced, for instance, in Colombia, where flexibility is abundant, due to the large hydropower component of the system. Another system may have sufficient capacity to cover peaks, but most of this capacity may be unable to ramp fast enough in case of unexpected events, causing flexibility issues that are better captured by the balancing or the real-time market, which should be used as the reference. This design was selected, for example, in ISO New England. Furthermore, the regulator may also decide to settle the reliability option on multiple reference markets, thus covering a variety of different scarcity conditions. Under this approach, implemented in Ireland and Italy, the RO sold by each resource is settled at the price of the market segment where the firm capacity of the resource was cleared[7].

Beyond the kind of scarcity conditions targeted by the CRM, the decision on the reference market can be influenced by several aspects, as the existence of a sufficient market liquidity in the optimal reference market (the price in that market must be reflective of the real status of the system), and by colliding interests among the different parties concerned by the design of the RO. This latter aspect is very well illustrated by the Irish experience, where during the long consultation phase that preceded the introduction of the CRM, a clash was evidenced between the interests of market agents and those of the System Operator. Market agents preferred the day-ahead as the reference market, since they perceived that this option would limit the risk they were exposed to. The System Operator preferred the balancing market, since it believed that this design would increase the amount of flexible capacity it can rely on during stress events. In the middle of this clash, the regulatory authorities eventually decided to introduce a so-called split reference market, i.e., multiple reference markets. With this design, for volumes sold in the day-ahead, the RO is settled at the day-ahead market price, for volumes sold in the intraday market, the RO is settled at the intraday

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[7] For instance, a resource may be assigned a firm supply equal to 80 MW and signs a reliability option contract for this amount. In a certain hour, this resource is cleared 50 MW in the day-ahead market, where the clearing price is equal to 75 €/MWh, and 30 MW in the intraday market, where the clearing price is equal to 200 €/MWh. If the reliability option contract is based on multiple reference markets and its strike price is equal to 150 €/MWh, the RO would be activated only in the intraday market and the resource would have to return 30 MW · (200 - 150 €/MWh) = 1 500 €.

market price, while any remaining RO volume is eventually settled at the price of the balancing market, which acts as some sort of last-resort reference market. The regulatory authorities of the island mentioned two main reasons to prefer this approach.

- It is hard to forecast which scarcity conditions the system will have to face in the future. The selection of a split reference market allows to encompass a broad variety of different stress events and it is likely to result in a higher reliability of the system.
- The Irish electricity market needs a competitive retailing market. Suppliers are expected to participate more actively than in the past in the wholesale market, including all market segments. A split reference market provides a financial hedge to suppliers regardless of the market segment where their demand was cleared. Any other design would negatively affect the incentive that these agents have to participate efficiently in the market.

Some agents pointed out that the split reference market design increases the risk for inflexible generation facilities. If these units are not cleared in the day-ahead market (for instance, due to low demand) and a stress event occurs in the intraday horizon, pushing the price in the balancing market above the strike price, they will have their RO settled at the balancing market price, even if they are not receiving those revenues. The regulatory authorities admitted that this risk exists, but that it reflects the worse contribution to security of supply that inflexible plants can provide to the Irish system compared to flexible resources. Inflexible plants should internalise this risk in their bids for reliability options, resulting in larger premia and having a lower probability of being cleared in the capacity market.

Italy, where the discussion regarding the design of the CRM initiated much earlier than in Ireland, eventually opted for a very similar design, with RO volumes being settled at the market price of the market segment where they were cleared. In the Italian case, however, the RO volume that has not been cleared in any market segment is settled at an administrative price[8], without a market segment acting as the last-resort reference (Mastropietro et al., 2018).

[8] The value of this administrative value is defined through a complex set of rules that aim to reflect the level of stress that the system is suffering.

Belgium, the last European power system to introduce reliability options, decided to have ROs settled at the day-ahead market price. Several reasons were mentioned for the selection of the day-ahead as the reference market.

- The security of supply problem in Belgium is characterised by a lack of adequacy, mainly due to the expected phase-out of nuclear power plants. The day-ahead market will rise above the strike when the adequacy of the system is at risk.
- Since the security of supply problem is related to adequacy, also slow-ramping and inflexible resources could contribute to solve it. A day-ahead reference market reduces the risk for these technologies and encourages their participation in the CRM.
- The Belgian electricity system is based on a self-dispatch model and centralised markets are used to settle portfolio imbalances. This results in a lower liquidity if compared with other European markets. The day-ahead market is the one that shows the higher liquidity compared to other segments, with a traded volume estimated at 25-30% of the total load (Elia, 2019a).

It must be remarked that, despite the low liquidity, Belgium has two day-ahead markets, since there are two different market operators (power exchanges) active in the country, EPEX and Nord Pool Spot. Therefore, market agents who want to sell ROs have to specify, in the qualification phase, in which day-ahead market they usually trade their energy, and their options will be settled at the corresponding market price.

3.2 Penalties and stop-loss mechanisms

Penalties and performance incentives are an essential feature in the design of any kind of capacity mechanism. The Clean Energy Package (CE, 2019) underlined the importance of sanctions, imposing that any capacity mechanism shall "apply appropriate penalties to capacity providers that are not available in times of system stress". Penalties usually convey the economic signal that is supposed to incentivise capacity providers to be available when the system needs them. They increase the risk perceived by the agents, but this can be limited through the application of a so-called stop-loss mechanism.

As mentioned in section 2, the original design of reliability options reinforced the signal sent by the option settlement with an explicit penalty for non-compliance. For a RO holder (the party who sells the RO) who cannot deliver its full commitment, the option settlement can be seen as an obligation to buy in the market the capacity that it is not able to produce through its assets. However, this might not be a sufficient incentive to be available at times of system stress. If only the uncovered option settlement is applied, the RO holder would have the same economic incentive to produce during scarcity conditions as an agent who did not sign a reliability option[9]. This would be reasonable only if the scarcity price is able to reflect the real utility function of demand. If this is not the case (as in most electricity markets with administratively-set price caps), it may be necessary to strengthen the signal and transform the financial contract in a physical contract that improves the reliability of the system.

This being said, most of the RO schemes implemented to date did not include an explicit penalty in their design. In Colombia, this lack of a penalty scheme was claimed to have provoked an inefficient dispatch of hydropower resources during the prolonged scarcity condition of 2010, due to *El Niño* phenomenon (dry year). The Colombian market monitor (CSMEM, 2010) stated that hydropower units preferred to honour their bilateral contracts instead of saving water in the reservoirs to be able to honour their ROs in the following months and that this behaviour was due to the lack of an explicit penalty. Also ISO New England found that the signal that was being sent by their reliability options was not strong enough to incentivise the availability of committed resources. Therefore, the regulator decided to reform its capacity market and, under the pay-for-performance paradigm, introduced large explicit penalties for non-compliance (Mastropietro et al., 2017).

An innovative sanctioning approach was followed by Ireland (I-SEM, 2015). In this power system, the regulators decided not to introduce an explicit penalty, but rather to "boost" the uncovered option settlement through Administrative Scarcity Pricing[10] (ASP). As mentioned in subsection 3.1, the balancing market acts as some sort last-resort reference market for Irish ROs and its price is used to settle any part of the committed capacity that has not been cleared in any market segment. Whenever the demand for capacity reserves is not met, the price in the balancing market is set administratively through a curve defined

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[9] If the reference market price is 1 000 €/MWh and the strike price of the option is equal to 300 €/MWh, the RO holder would earn 300 €/MWh if it produces and would lose 700 €/MWh if it does not produce, while an agent who did not sign a reliability option would earn 1 000 €/MWh if it produces and would earn 0 €/MWh if it does not produce. The difference between producing and not producing is, in both cases, a net loss of 1 000 €/MWh.

[10] In the academic literature, this concept is used as a generalisation of pricing methods like the Operating Reserve Demand Curves (ORCD) used in some systems in the United States (Bajo-Buenestado, 2021).

by the regulators. This curve reaches almost 3 000 €/MWh (which is 25% of the Value of Lost Load, or VoLL) when there is no capacity reserve and rationing is likely to occur. This maximum value should grow in the future, eventually reaching the full VoLL. Italy follows a similar approach but without a proper ASP mechanism, by setting administratively the price for the uncovered option settlement in some specific conditions (as in case of power rationing). With this approach, the economic signal is sent only to RO holders and it does not affect the operation of resources not involved in the CRM.

Belgian reliability options do rely on a penalty scheme, but its application goes beyond the scarcity conditions identified by the strike price. Besides this latter threshold, the Belgian regulator introduced a lower cut-off point, the so-called Availability Monitoring Trigger (AMT) price[11]. When the price of the reference market (in this case, the day-ahead market) exceeds the AMT price, the availability of RO holder will be monitored. Also testing outside of these settlement periods is possible. Any difference between the capacity commitment and the capacity available during monitoring is penalised through an explicit penalty that is computed based on the yearly contract value (Elia, 2019b).

3.2.1 Stop-loss mechanisms

Although penalties are an essential element of capacity mechanisms, it may be efficient to reduce to a certain extent the risk that market agents perceive due to their application. Most of RO schemes, as other CRM designs, rely on a stop-loss mechanism, which limits the economic loss that an agent may be subject to due to its reliability options. This economic loss can be due to i) uncovered option settlement, i.e., a situation in which the resource does not deliver its firm supply, does not receive the reference market price, but it has to return anyway the difference between this price and the strike price; or ii) explicit penalties for underperformance.

Stop-loss mechanisms set a cap to the cumulative amount of the economic loss over a certain period. A common approach is to have two caps, one for the short term (e.g., the cumulative economic loss over a week or month cannot exceed a certain value) and one for the entire delivery period, usually one year. In European RO schemes, these limits are commonly expressed as a percentage of the yearly option premium obtained by each resource. For

[11] During the consultation phase, the AMT value being discussed was almost one third of the RO strike price (Elia, 2019b).

instance, in Belgium the yearly stop-loss is equal to 100% of the yearly option premium (Elia, 2019b), thus RO holders cannot lose more than they earned upfront through the premium. In Ireland, this value was set at 150% of the yearly option premium (I-SEM, 2015). In ISO New England (2018), as in other capacity markets in the Unites States, the stop-loss value is set based on the starting price of the capacity auction, which is usually computed as a percentage of the Cost of New Entry (CONE).

3.3 Load-following or fixed obligations

Both the option settlement and, when underperformance is registered, the explicit penalty can be applied, in every settlement period, according to the entire capacity commitment, i.e., the volume of ROs that each resource has sold in the CRM and is remunerated for. This approach constitutes a fixed obligation for the capacity provider. However, the regulator may decide that the volume that must be delivered in each settlement period has to be adjusted according to the conditions in the system and be lower than the entire capacity commitment. The main reason for introducing these rules is that scarcity conditions, as identified by the reference market price, can occur at a time when the load is lower than the peak demand which the CRM was dimensioned for. If, in this situation, all RO holders were required to deliver their entire capacity commitment, some of them would not be able to be cleared in the market and may be inefficiently penalised.

In order to avoid this inefficiency, the capacity commitment may be reduced through a scaling factor. This factor may be computed as the actual load (or, in certain designs, the demand cleared in the reference market) divided by the demand cleared in the CRM auction. The capacity commitment can be also scaled down to consider the presence in the system of resources that did not sign a reliability option, but which may be producing at a low cost in a certain settlement period. For instance, intermittent renewables are usually assigned low de-rating factors and low firm capacities in Europe, but they may be producing at their full capacity during a certain stress event. A subtracting element can be included in the settlement formulas to take this effect into account.

The Colombian, Irish and Italian reliability options are load-following. The Irish regulators justified this decision by stating that, with a fixed obligation, the option settlement may create some sort of "windfall gains" for demand[12], while the objective of mechanism is to guarantee a proper hedge against high prices (I-SEM, 2015). In Belgium, the possibility of a load-following obligation was considered in the consultation phase, but the final design eventually introduced a fixed obligation, reflecting the pure adequacy concerns that the CRM is meant to address.

3.4 Strike price and indexation

Another key element in the design of a reliability option is the definition of the strike price for the call option settlement. As already mentioned, this strike price is not just a parameter of the financial contract, but it becomes the trigger that allows to identify scarcity events, during which committed resources will have to deliver their firm supply. It may be seen as the frontier between the normal operation of the system through the energy market and a scarcity event that should activate the capacity mechanism.

It must be remarked that the objective of a CRM is to improve the reliability of the system, not the affordability of electricity supply as such. The latter objective is of utter importance in decarbonising power sectors, especially in the context of the current energy crisis, but it should be pursued through different mechanisms[13]. One of the most beneficial features of ROs is their ability of minimising the interference with the normal operation of the energy market. They should only be activated when the security of supply is at risk, via a market price able to reflect these critical periods. For these principles to be fulfilled, the strike price should be set high enough to allow an efficient functioning of the energy market. Furthermore, it should be subject to an indexation formula that allows to internalise any relevant change in the underlying costs.

3.4.1 Setting the strike price

The original RO design (Vázquez et al., 2002) proposed to set the strike price beyond the variable costs of the vast majority of the resources in the generation mix (e.g., 25% above

[12] When the load is lower than the peak demand which the CRM was dimensioned for, a fixed obligation would require committed resources to settle the option for their entire capacity commitment, providing a financial hedge that is higher than the one needed by the actual demand registered in the system.

[13] See the discussion in BEIS (2022), ACER (2022b) and the proposals from Batlle et al. (2022b, c) to introduce affordability options, i.e., specific call options with a long-term settlement that would provide a hedge to consumers.

the variable cost of the most expensive resource expected to produce during the delivery period). Most of the capacity mechanisms based on ROs have followed one way or another this suggestion. Colombia originally defined the strike price as the variable cost of the least-efficient generation technology, running on fuel oil. In ISO New England, the strike price was set through a proxy unit running on fuel oil or gas, whichever had a higher cost. In Italy, the strike price is set before each auction at the variable cost of the technology with the lowest investment costs in the system, currently a gas turbine. In Ireland, the same approach was applied, but with an innovative feature. The strike price is defined as the variable cost of a low-efficiency plant, running on either gas or fuel oil, but it also has a minimum value, which reflects the activation costs of a reference demand-response (DR) unit. The addition of such a floor was meant to guarantee the technology neutrality of the CRM and to maximise the potential contribution of demand resources to the capacity market.

The only power system that does not rely on the variable or activation costs of a reference technology to compute the strike price of the reliability options is the Belgian one. The discussion on the definition of the strike price in this system was influenced by the motivation behind the introduction of the CRM. Beyond guaranteeing the security of electricity supply, Belgian reliability options have a secondary objective, i.e., to avoid windfall profits. According to Elia (2019a), windfall profits arise when inframarginal rents reach levels that were not counted upon initially when investing in the capacity. However, inframarginal rents vary among different technologies. Therefore, the first discussion that the policymaker had on this design element was whether to have a unique strike price or a different strike price for each technology. Although this possibility was assessed in the academic literature (Woodhouse, 2016), it was never contemplated for real CRMs. The reliability product traded in the capacity market should reflect the contribution of resources to the security of supply and, therefore, it should be the same for all resources. In the case of reliability options, this means that the strike price should be unique. Any other approach would mean procuring different products from different resources, with the problem of comparing these products if they are supposed to be purchased in the same centralised auction[14].

The Belgian policymaker was aware of these criticalities. It was also aware that, if different strike prices were set, then also the price cap in the auction would have to be differentiated per technology. Eventually, this approach would lead to several administrative decisions that would transform the scheme in a full revenue regulation, which is obviously not the goal of a CRM in a liberalised power sector. Therefore, the policymaker decided to have a unique strike price for all technologies. However, during the consultation phase, an exception was introduced to this rule, in order to allow demand-response resources to include their own strike price as a complement of the price-quantity bid they submit to the auction for ROs (as a so-called Declared Market Price, or DMP). This strike price should be reflective of their activation costs. For the rest of the technologies, the strike price is not set based on a reference technology or a proxy unit, as in other RO schemes, but rather through an econometric analysis of day-ahead market prices registered in the past. The objective is to select a value that ensures that a reasonable volume of capacity offered in the day-ahead market would be cleared prior to reaching the strike price. As it is analysed hereunder, this heterodox approach was not resilient to the energy crisis experienced in Europe in 2022.

3.4.2 Indexation of the strike price

For reliability options not to interfere with the energy market in normal conditions (when the system is not under stress), the strike price should be subject to an indexation formula that allows to reflect the main changes in the variables used to set the strike in the first place. Since most of RO strike prices to date have been set considering a reference technology, commonly a thermal power plant, the main element of this indexation is certainly represented by fuel costs. Another element of these formulas, in European RO mechanisms, is the cost of carbon emission allowances. The regulator should also make sure that the variables of the indexation formula cannot be influenced by RO holders, who could

[14] A possible solution could be to internalise the strike price offered by each resource in the de-rating process, recognising a lower firm supply to resources that bid a higher strike price. However, this approach has never been used in real CRMs and it could make the de-rating process and the auction clearing much more complex.

otherwise try to artificially increase the strike price for the call option not to be activated in the market.

The importance of accurate indexation formulas has been demonstrated by recent developments in international experiences. The strike price of Colombian ROs was indexed to the price of fuel oil no. 6 on international markets. The international price for this fuel had a strong decreasing trend after 2012. However, the same decline was not registered in the price of this fuel (and other fossil fuels for electricity generation) in the Colombian market. Therefore, the strike price dropped, but the variable costs of thermal power plants did not have the same evolution and, in several periods, they were much higher than the strike price. When the Colombian power system underwent *El Niño* phenomenon (dry year) in 2015/2016 and reliability options were activated, this inaccuracy in the indexation formula made RO contracts unsustainable for some market agents. In fact, several thermal power plants were facing a net economic loss to honour their reliability options. The evolution of the spot price (light blue area), the strike price (orange line, updated monthly) and the bids of different technologies in the energy market during *El Niño* phenomenon can be observed in Figure 4. In order to avoid similar inefficiencies in the future, the Colombian regulator was forced to reform the strike price calculation methodology[15].

[15] The mechanism now relies on two different strike prices. The first one is the original one, indexed to fuel oil no. 6. The second one is calculated as a percentile of the variable costs of those resources who signed a reliability option. The former is applied to ROs signed before 2019. The latter, usually higher than the former, is applied to new RO contracts (CREG, 2016).

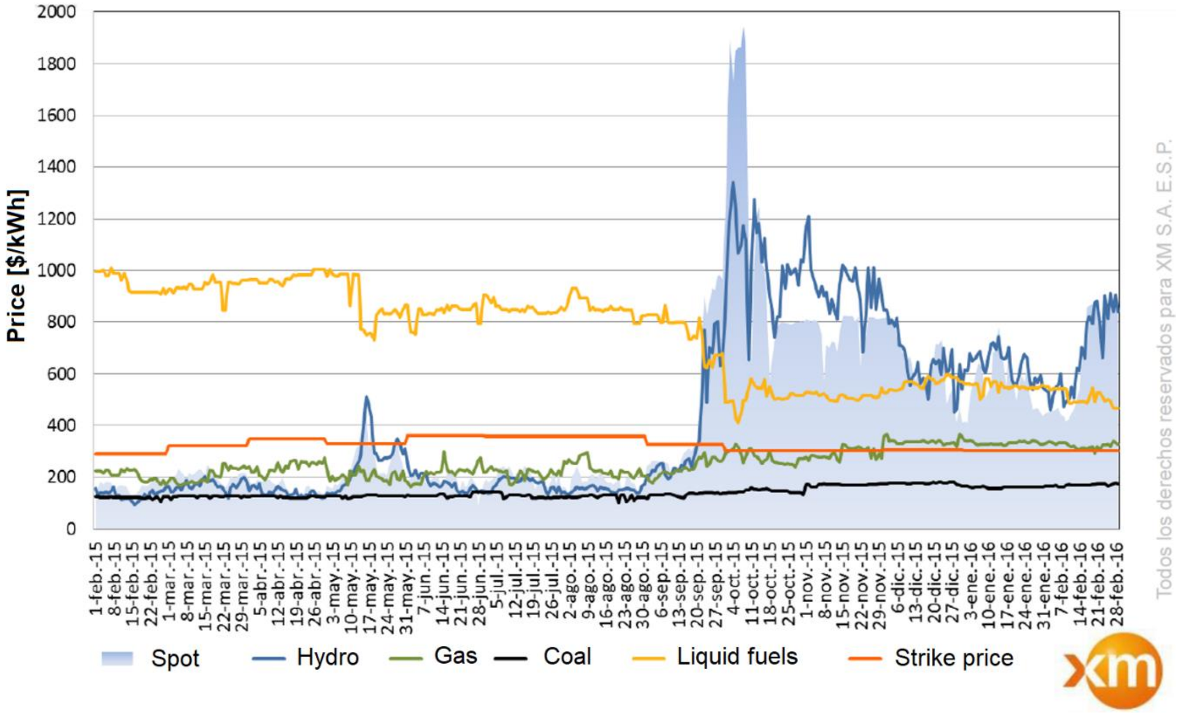

Figure 4. Evolution relevant prices and bids during *El Niño* phenomenon 2015-2016; adaptation from XM chart

Also European RO mechanisms have been put to the test by the 2022 energy crisis. The indexation formulas of the Irish and the Italian ROs allowed to internalise the escalation in the price of natural gas. The call options in these two power systems were rarely activated, since the strike price followed the increase in the underlying costs. From a regulatory point of view, this was the correct outcome, since the European Union was undergoing an affordability crisis, not an adequacy one. However, some adjustments in the indexation formulas were required. Italy, for instance, increased the frequency with which the natural gas component of the strike price is updated (ARERA, 2022).

The 2022 energy crisis also challenged the Belgian RO mechanism. The choice of setting the strike price based on the day-ahead market prices registered in the past was not sustainable in a scenario of skyrocketing electricity prices. The first delivery year of the Belgian CRM is 2025. At this writing, the proposal is to divide the strike price computed before the crisis for the first RO contracts into two components, a fixed and a variable one. The variable component would be updated ex-post, according to the day-ahead market price registered in each month (Elia, 2022). This means that the strike price of the Belgian ROs would only be known several days after the operation of the power sector, losing its original role of indicator of system stress in the real time.

3.5 Financial hedge for consumers

Reliability options provide a financial hedge against high electricity prices (associated with scarcity conditions) to the demand covered by the mechanism. However, this financial hedge is not always direct. RO holders must return the difference between the reference market price and the strike price through the option settlement. The option settlement can be transferred to consumers (direct hedge), so that they eventually cover their demand at the strike price of the call option. However, the revenues from the option settlement can also be used by the system operator, who usually represents the whole-system demand in the CRM, to reduce the net costs of the mechanism (indirect hedge). In this case, the money collected through the option settlement and, if they are applied, explicit penalties is subtracted from the overall cost of the option premia paid to RO holders, and this allows to reduce CRM charges.

Both approaches can be found in international experiences. In ISO New England, Italy and Belgium, the RO financial hedge is indirect and the option settlement is used to reduce CRM charges. In Colombia and Ireland, the hedge is direct and the option settlement is used to reduce the price paid by consumers in the wholesale market. In Ireland, this approach gave rise to a further discussion, i.e., the necessity to avoid the risk of a "hole in the hedge" (I-SEM, 2016). The latter can be defined as a situation in which the difference payments from RO holders (the Irish terminology for the option settlement) are not sufficient to provide a hedge to the entire demand in a certain settlement period. This can occur, among other situations, due to large generation shares from intermittent renewables during scarcity conditions. These resources are assigned low de-rating factors, thus they would return only a small difference payment compared to their market incomes. A hole in the hedge could also be produced by the stop-loss mechanism, which may reduce uncovered difference payments (subsection 3.2) when the cumulative penalties applied to a certain market agent reach a pre-defined threshold. Irish regulators decided that difference payments from RO holders have to be complemented, if needed, in order to guarantee a full hedge for the entire demand covered by the CRM. This complementary cash flow is to be covered through an additive element in CRM charges, thus being socialised among consumers.

3.6 Interaction with long-term contracts

Reliability options are a long-term contract. They can be signed several years in advance of the delivery period and their duration can span from one to more than ten years (for new resources). Reliability options can therefore interact with other long-term contracts that their holders may sign for the same delivery period. For instance, an RO holder may sign a long-term energy contract (e.g., a two-way contract for difference at a certain contract price) based on the same reference market of the reliability option (e.g., the day-ahead market). Whenever the reference market price exceeds the strike price of the RO, this agent will have to return the difference between the market and the strike price to the CRM operator and the difference between the market and the contract price to the counterparty of the long-term contract. The agent cannot be the natural counterparty of both contracts, since it receives the remuneration from the market only once. This significantly increases the associated risk.

The potential interaction between reliability options and long-term contracts has always been controversial in the design phase of RO capacity mechanisms. Market agents usually call for rules that exempt RO holders from difference payments in case their remuneration in the reference market is being limited by a long-term contract. However, most of RO schemes implemented to date did not apply this kind of exemptions. According to the Belgian policymaker, signing long-term contracts is part of the risk-hedging strategy of each market agent and very different strategies are possible. Therefore, it is not possible nor desirable to internalise long-term contracts in the settlement of reliability options. Irish regulators recognised the risk that an agent who signs both a reliability option and a long-term contract may face, but they suggested that market agents should solve this problem by offering consumers long-term contracts that are settled only up to the strike price of the RO, since, from that price on, consumers would be covered by the reliability option. It must be underlined that this design would be possible due to the direct financial hedge that Irish ROs provide to consumers (subsection 3.5).

Finally, it must be remarked that most RO contracts are signed several years in advance of the delivery period. At the same time, the liquidity of long-term electricity markets sharply decline beyond the two- or three-year time horizon. Therefore, market agents should be able to reorientate their contracting strategy (or to redesign their contracts), considering the reliability options they have signed, before the delivery period.

4 REGULATORY RECOMMENDATIONS

Based on the comprehensive assessment of the design elements of reliability options presented in section 3, some regulatory recommendations are drawn in this section. For some design elements, it is not possible to define an optimal design, since an equilibrium among different regulatory objectives has to be pursued. For other features, both regulatory theory and international experiences show more clearly the benefit of a certain option.

The selection of the reference market is a key choice that the regulator has to make when introducing reliability options. It is not possible to define an optimal design, since diverse regulatory goals may be involved in the selection. Hereunder, these conflicting objectives are listed together with the RO design that may favour their achievement.

- Maximise the financial hedge for consumers during scarcity conditions. The selection of a single reference market may provide a more complete coverage from high prices to those consumers who are able to purchase most of their demand in the reference market.
- Minimise the risk perceived by market agents. Market agents may have different characteristics that have an impact on the perceived risk. Inflexible resources may be favoured by a single reference market far from the real-time operation, as the day-ahead. Flexible resources may be favoured by the selection of multiple reference markets (if the day-ahead market signals scarcity conditions and they have not been cleared, they have time to react, be cleared in subsequent auctions, and fulfil their commitment). All resources would perceive a lower risk with load-following obligations.
- Minimise the alteration of the liquidity equilibrium among different market segments. The selection of a single reference market tends to concentrate the liquidity of the wholesale market in that specific market segment. Multiple reference markets may allow RO counterparties to follow their usual bidding strategy, without altering the equilibrium among market segments.
- Provide coverage from scarcity events whose nature could be uncertain. ROs based on a single reference market protect the system against the type of scarcity conditions that are revealed by that market segment (e.g., adequacy issues for the day-ahead market). When the uncertainty on the kind of scarcity conditions that are expected in the future is large, a design based on multiple reference market may provide a better coverage.

As regards penalties for under-performance, there are two approaches that can be efficiently applied: i) the “orthodox” explicit penalty and ii) the reinforcement of the “implicit” penalty represented by an uncovered option settlement through administrative scarcity pricing. ASP may be more complex to implement, since the regulator must define in which market segment it is applied (preferably, in the reference market itself) and whether and how this signal should be transferred to other market segments. Once implemented, ASP has the advantage of sending the signal that the system is under stress to all resources in the system, not just to RO holders[16]. Furthermore, if an ASP curve is defined, the penalty will not be fixed, but would grow as the scarcity condition becomes more severe (although the same effect could be obtained through an explicit penalty with a variable penalty rate). Orthodox explicit penalties have the advantage of being included in the RO contract. Therefore, they are not subject to subsequent changes in the market design. Explicit penalties are also more aligned with the underlying principles of reliability options. In fact, they can be applied based solely on market prices, without recurring to technical parameters, which are commonly used to activate ASP. In both cases, the penalty rate or the full administrative scarcity price should reflect the economic damage that the underperformance of the RO holder is causing to the system. The parameter that best reflects this damage is certainly the VoLL[17].

Stop-loss mechanisms may be very relevant in reducing the risk perceived by market agents, especially if strong penalty schemes are introduced. However, there is no theoretical justification for setting a limit to the economic loss that a RO holder can face equal to the total option premium. This approach could incentivise opportunistic behaviours. A more efficient alternative is to define the cap on losses according to the CONE used to define price cap in the RO auction. This parameter may change from auction to auction, but it is not very volatile and guarantees that resources who signed reliability options in different auctions face similar conditions. The stop-loss mechanism should also include some rules that still provide resources that achieved the cap with incentives to continue delivering their firm supply[18].

As regards the strike price, it must be remarked that the value of ROs is affected by the strike price. The higher the strike price, the lower the value of the RO for consumers and the lower the premium that resources require to sell it. The first recommendation, therefore,

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[16] This is true only if market agents can have access to the administrative scarcity price. For instance, if ASP is applied only to the imbalance settlement price, it may be too risky for market agents to try to have access to that remuneration.

[17] This recommendation is based on the presumption that a reflective VoLL is calculated for the power system. Ideally, the VoLL should not be computed as a single value, but as a function of the lost load (Gorman, 2022).

[18] This could be achieved, for instance, through over-performance payments. See Mastropietro et al. (2017) for details.

is to set a unique strike price for all the resources and technologies participating in the CRM. This is especially relevant for centralised RO mechanism. Multiple strike prices imply multiple reliability products, which could not and should not be procured in the same auction as equivalent products.

International experiences showed that the best approach to define the strike price is to use a proxy unit with high variable costs. The proxy unit should be defined before each auction and it should not be modified for the contracts signed in that tender. In fact, the strike price has a significant impact on the bid that market agents submit in the auction and they should be able to forecast its evolution over time. Also the indexation formula should be known in advance and it should encompass all the items that can affect the variable costs of the proxy unit. The indexes used in the formula should be able to reflect the changes in these cost items that are actually being experienced in the power sector (e.g., avoiding international prices that may not be fully correlated with domestic prices). The frequency of the updates should be sufficiently high to reflect any relevant cost change. The strike price definition and the indexation formula should allow RO holders to know the strike price well in advance of the operation of the reference market, for them to estimate when the reliability option could be activated and their firm supply required.

Commonly, low-efficiency thermal power plants have been used as proxy units to compute the RO strike price. According to some regulators, this approach may disincentivise the participation of demand-response resources, which may have activation costs higher than the strike price. For this reason, some policymakers, as in Ireland, introduced a floor in the strike price calculation, which reflects the activation cost of a representative DR resource. However, DR resources may have a very wide range of activation costs. The selection of the representative activation cost, therefore, should pursue an equilibrium between two conflicting goals, i.e., i) removing barriers for demand participation in the CRM and ii) setting a very high strike price that does not provide a sufficient financial hedge to consumers. This task may be further complicated by the lack of reliable data and estimations on the activation costs of DR resources in the power sector. Finally, it may be hard to define an indexation formula for the activation costs of demand response. All these complexities suggest that the selection of DR resources as proxy units for the strike price calculation is a decision that should be taken with caution, subject to a comprehensive evaluation of benefits and risks.

Alternative approaches for the definition of the strike price that do not rely on a proxy unit, as the Belgian RO strike price based on historical day-ahead market prices, revealed important inefficiencies in periods when significant changes in the price dynamics are registered, as during the 2022 energy crisis.

As regards the financial hedge for consumers, two approaches have been presented, i.e., i) a direct coverage, through which consumers receive the option settlement from RO holders in each settlement period when the market price exceeded the strike, and ii) an indirect coverage, which consists in using the settlement of ROs to reduce CRM charges. Although the second design is more commonly found in international experiences, a direct coverage may facilitate the settlement of other long-term contracts that generators and consumers may have signed. These contracts are part of the risk-hedging strategy of each market agent, they have very heterogeneous designs, and they cannot be internalised in the settlement of the reliability options. However, if a direct financial hedge is provided to consumers, it is possible to internalise the RO in the new long-term contracts that are signed after the introduction of the CRM, so that these contracts are settled only up to strike price of the reliability option. Another potential advantage of direct coverage is that it could result in a better acceptance of the CRM among consumers.

Finally, it must be remarked that the design elements of reliability options present several interdependencies, as graphically illustrated in Figure 5. For example, the selection of a reference market that focuses on scarcities related to adequacy issues, such as the day-ahead, is more likely to be associated with fixed obligations (as adequacy scarcities are likely to require the full firm supply of the system to be solved). On the other hand, a reference market that is closer to the real-time operation may signal scarcity conditions that are more related to a lack of flexibility, which can also be registered outside peak hours, improving the case for load-following obligations. At the same time, selecting the balancing or the real-time market as a reference may also favour the adoption of penalty schemes based on administrative scarcity pricing, which is commonly applied in these market segments. Moving to the right part of Figure 5, as mentioned above, a direct hedge for consumers may favour the harmonisation of long-term contracts with the settlement of reliability options. Although the relationship is not direct, these dependencies can also be observed in the international experiences analysed in this article, as shown in Table ii.

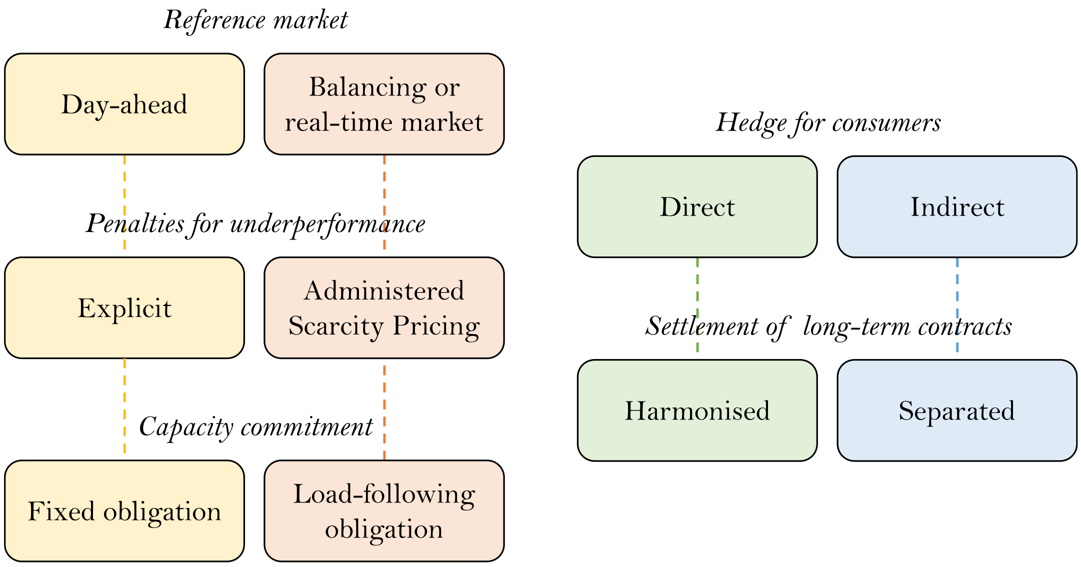

Figure 5. Potential dependencies among the design elements of reliability options

5 CONCLUSION AND POLICY IMPLICATIONS

The role of capacity mechanisms in liberalised power sectors is expected to grow in the next decades. Beyond the market reforms that may be undertaken, especially in Europe, as a response to the 2022 energy crisis[19], the energy transition calls for long-term instruments that drive the system towards a reliable resource mix. Reliability options are a type of reliability product to be traded in CRMs that is gaining consensus because of the low interference with the energy market. ROs also present other advantages if compared with other reliability products, in terms of resiliency to an increase in demand elasticity, efficient cross-border participation, and reduction of market power. Originally introduced in Colombia in 2006, reliability options are now widespread in Europe, where they have been implemented in three power sectors: Ireland, Italy, and Belgium.

This article provides a comprehensive assessment of the design elements of reliability options, revealing the broad variety of different designs that can hide behind the RO label. For each design element, the article provides first a theoretical background that should guide the selection of the optimal design and then presents some practical implementation problems and discussions from the review of international experiences. This approach allows some pragmatic recommendations to be made, which are presented below.

[19] See Chaves-Ávila et al. (2023) and Batlle et al. (2023) for an assessment.

Reliability options are physical call options that require the holder to deliver its firm supply whenever a reference market price exceeds a predefined strike price and to return to the counterparty (commonly the system operator) the difference between the market and the strike price, i.e., the option settlement. The main alternatives for the selection of the reference market are a single reference market, further or closer to the real-time operation of the system, or multiple reference markets. The selection of the reference market should pursue an equilibrium among conflicting objectives, such as the maximisation of the financial hedge for consumers, the minimisation of the risk perceived by market agents, or the need not to alter the equilibrium between different market segments.

Reliability options should include penalties for underperformance. This can be achieved either through an explicit penalty that is applied when the RO holder is not producing during scarcity conditions or through the application of administrative scarcity pricing in the reference market, which strengthens the signal sent by the option settlement. Both approaches, if properly designed, provide similar outcomes, but it is important that the penalty is proportional to the economic damage that the underperformance may actually provoke. If this approach increases the risk perceived by market agents, the latter may be reduced through a stop-loss mechanism, with a cumulative loss threshold proportional to the cost of new entry.

The strike price of the call option should be the same for all RO holders cleared in the same auction. In fact, different strike prices would generate different reliability products and the latter should not be procured in the same tender as equivalent services. The best approach to define the strike price is to use the variable costs of a proxy unit, commonly a low-efficiency thermal power plant. The strike price should be subject to an indexation formula that includes all the relevant cost items and be updated with sufficient frequency to reflect any expected non-negligible change. The strike price may also internalise the activation costs of demand response, but this design implies some complexity and should only be introduced after a comprehensive assessment of the benefits and risks.

The hedge provided to consumers through ROs should be direct, i.e., the option settlement should be made directly available to end-users in each settlement period, thus reducing the price they pay in the energy market. This approach can facilitate the settlement of other long-term contracts that generators and consumers may have signed.

The recommendations drawn in this article may be useful for regulators and policymakers interested in introducing reliability options in their power sectors. For the sake of conciseness, this article has intentionally not delved into the participation of non-conventional resources in RO schemes. The design of reliability options may have an impact on the kind of participation that can be expected by intermittent renewables, demand response, storage assets, or even by cross-border resources. Some European regulators have decided to loosen some RO contract requirement to foster the participation of these technologies in the CRM. Future research should focus on this topic, reviewing the different approaches that can be found in Europe and assessing the pros and cons of defining specific RO products for non-conventional resources. Another area for future work is an analysis of how capacity remuneration mechanisms based on other reliability products can transition towards reliability options, thereby introducing a financial hedge for consumers.

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