Innovating the electricity market design to achieve an efficient decarbonisation process

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The electricity market was designed to pursue multiple objectives, including those of efficiency (productive and allocative, in the short and in the long term) through the promotion of competition. These traditional objectives have been complemented by an additional one, decarbonisation, which, in recent years, has taken a predominant role. This new goal has relevant implications for the electricity market design: it requires a progressive and significant increase in the share of electricity produced from renewable sources, which in turn impacts the ability of the wholesale spot electricity markets to provide the correct signals both in the short and long term.

The increasing share of electricity produced from renewable sources (hereinafter designated RES) - mostly non-programmable and distributed - requires evaluating the opportunity - if not the need - to proceed with a review of the market design of the electricity wholesale markets.
In fact, for a market design to effectively achieve the objectives of efficiency and competition, it must be built taking into due consideration the technical and economic constraints that characterise the system and its resources.

In this respect, reaching the decarbonisation objectives and the related development of renewables introduces a series of problems in terms of the adequacy and security of the system, so far neglected in the design of the wholesale power market. The current market design is almost exclusively focused on spot markets (energy and ancillary services) and assumes that the price signals provided by the spot markets are able to ensure the availability (in real time) of an adequate mix of resources. At the time of the liberalisation of the European electricity market, this assumption was acceptable, considering that:

- the entry of new market players (with conventional generation sources) was ensured by the greater efficiency of the new plants; and
- no security issues arose, as correctly planned systems were inherited, with traditional generation plants capable of providing all the ancillary services that the system needed in order to be managed in a secure way.

Yet, the current market design is already showing its shortcomings[1] and seems hardly compatible with the pursuit of decarbonisation goals. In fact, as we will see hereafter, the development of renewables emphasises the inability of wholesale markets to provide, through spot prices only, an effective incentive to stimulate an adequate level of investment in new generation capacity 'at the right time, in the right places, and using the right technologies'[2]. This failure becomes particularly critical today to the extent that the progressive increase in the penetration of production from not fully dispatchable RES creates the need to integrate additional resources into the generation portfolio. These additional resources are not only needed to ensure the adequacy, but also the security of the system. Moreover, given their cost structure (high fixed costs) and the high unpredictability of their value - which mostly depends on exogenous variables and on the System Operator (hereinafter "SO") action in the ancillary services market – an appropriate level of investment in these resources can hardly be reached on a merchant basis with the current market design.

[1] For instance, the problems related to the adequacy of the system and the full integration of RES generation units into the market

[2] P. Joskow, Competitive electricity markets and investment in new generating capacity, MIT 12th June 2006

We therefore envisage the introduction of new forward contracting mechanisms and the opportunity to innovate existing ones[3]. This should be done in order to:

- ensure the availability of a minimum quantity of resources with the aim of maintaining system security and adequacy whilst achieving the decarbonisation objectives.
- create an 'environment' that, leveraging on available assets, is capable of promoting merchant initiatives for the development of renewables and storage, for example via Power Purchase Agreements (hereinafter designated PPAs); that is to say that centralised forward contracts should not eliminate the space for merchant initiatives, but limit themselves to what is strictly necessary to encourage the development of these initiatives;
- achieve efficient coordination between the various forward contracting mechanisms and market initiatives, to maximise synergies and allow a correct exploitation of the externalities that each of these produces on the others;
- ensure full compatibility with the functioning of the spot markets, so that they can express correct signals with respect to the actual value of resources in order to maximise short-term (productive and allocative) efficiency.

This work posits an evolution of the current electricity market design, one that would pursue the aforementioned objectives and provide long-term signals necessary to support investments in an efficient portfolio of resources in line with policy objectives. More precisely, we suggest the introduction of three distinct forward markets, placed in sequence over time, in order to ensure efficient coordination: the 'Pro-Security Forward Market'; the 'Pro-Decarbonisation Forward Market' and the 'Pro-Adequacy Forward Market'.
In the following sections we illustrate the overall logic of the proposed regulatory framework and the suite of individual tools that are part of it. Furthermore, we explain how the mechanisms should be 'interconnected' with each other, avoiding costly inefficiencies for the system.

1. The critical issues of a system characterised by high share of production from RES and the need to redesign the electricity market model

A generation fleet pivoting towards an 'unbalanced' mix that privileges wind and photovoltaic sources, poses critical issues both in terms of adequacy and in terms of security and quality of the electricity service.

This production capacity, in fact, is denoted by:

- non full dispatchability and unreliability of the source (the sun and the wind);
- variable costs practically equal to zero or, in any case, very low;
- limited ability to regulate frequency, inertia and voltage;
- being highly distributed.

Given these characteristics, in the presence of high levels of production from RES, the system is exposed to the following critical issues:

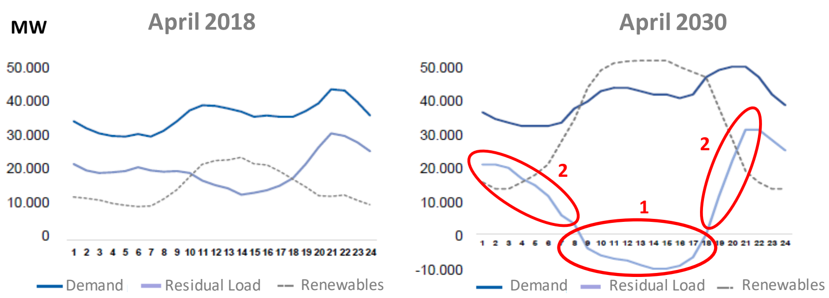
- overgeneration[4] in hours with high RES production and, on the other hand, problems to meet demand in hours in which these resources stop producing due to the unavailability of the

[3] We refer to the current support schemes for renewable production and the forward contracts for adequacy (so-called Capacity Market).
[4] Over-generation from RES is the amount of RES production exceeding the level consistent with the security of the system.

primary source (e.g.: evening ramp due to decrease in photovoltaic production, as shown in the following chart);

- reduction of the regulating power and reduction of the system inertia due to the closure or mothballing of large plants;
- reduction of peak demand reserve margins (system adequacy);
- increased network congestion, due to the unpredictability and the volatility of RES production (in time and space)

The growth of RES production and new needs for the power market



Source: Terna

1. **Overgeneration & price cannibalisation**: when RES production is higher than demand, system will have to cope with the **excess production** (reversely, during "**Dunkelflaute**" periods, backup generation has to support demand) → **Need for storage systems**
2. **Ramps**: in periods when RES production is increasing/diminishing, the **backup** (programmable!) production has to **react properly** (in terms of rapidity and quantity) in order to sustain loads → **Need for frequency and voltage regulation**

It follows that, in order to accommodate high levels of production from RES, the system, to the extent that it's not economic to overbuild RES capacity and, therefore, limit in many hours their admissible production ex-ante[5], must have at its disposal additional resources capable of: i) spreading renewable production over time and/or in space (to overcome the technical/physical and/or economic constraints that characterise these resources) as well as ii) guaranteeing the security, adequacy and quality of the electricity service.

More precisely, in order to achieve the decarbonisation objectives, preserving the security of the system, it is required that the mix of resources evolves to include:

I. RES production capacity consistent with renewable production targets;
II. enough storage resources (e.g. electrochemical, pumped hydro, power to gas[6]) and grid developments to ensure that the RES capacity can be optimally utilised (to the extent that it's not economic to overbuild RES capacity), avoiding to curtail renewable production needed to efficiently achieve the RES penetration target;

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[5] One possible scenario would be to limit, ex-ante, the admissible RES production, in order to ensure a minimum level of conventional generation that would: i) satisfy the demand in the hours of low RES production (also at local level, given the network constraints); ii. provide the necessary frequency and voltage regulation and reserve performances. Clearly this solution could be suboptimal with respect to the decarbonisation objective of reducing the production to zero carbon content.

[6] Power to gas technologies can be assimilated to storage so long as there is enough existing storage capacity.

III. enough resources[7] to provide ancillary services which would guarantee the system security, even in periods of extremely high RES production;
IV. sufficient resources to ensure the adequacy of the system.

Although there is common agreement on the need to integrate 'additional' resources into the electricity capacity mix to overcome the critical issues induced by high levels of "RES penetration", how these resources should be developed is still up for debate. Is it reasonable to expect that the market alone will promote sufficient investments to ensure the development of a generation portfolio consistent with both the decarbonisation objectives and the security and adequacy standards?

In this regard, it must be considered that, in a system with limited ability to allocate (at low cost) electricity over time (the so-called capacity constrained system), a high level of penetration of renewables suggests an increasing growth in the volatility and unpredictability of the value of electricity over time and/or in space[8]. In fact, the optimal generation mix that is able to meet demand while preserving the security of the system, can change at any given point in time and cannot be predicted accurately, as it depends on the availability of the primary RES source in the different periods/areas. In other words, the wholesale spot markets outcomes may vary between extremely low (even negative) prices, when the entire demand is met by RES, and high prices that reflect the higher short term marginal costs of, for example, an Open Cycle Gas Turbine (OCGT)[9].

It is therefore clear that a greater penetration of RES, on the one hand creates the need (also reflected in the price differentials between the diverse periods/areas) to integrate additional resources into the generation portfolio (such as storage) while on the other hand, renders market revenues highly uncertain and risky, thus discouraging merchant investments.

In this sense, increasingly greater RES penetration further exacerbates the inability of energy-only markets to provide the right price signals to guide investments towards an efficient generation (and storage) mix.

The original spot wholesale markets for energy and ancillary services were designed assuming that they could perform two related resource allocation functions:

- in the short-term, provide for the efficient real-time operation of existing generating capacity, clearing supply and demand at efficient wholesale prices that represent the marginal cost of supply at any moment;
- in the long-term, provide, through market prices and price expectations, efficient long run profit expectations and incentives to support efficient decentralised investment decisions.

Post-liberalisation experiences have highlighted a failure of these markets to perform this second function. Several economists[10] believe that the failure of wholesale markets to incentivise investments in an efficient generation portfolio through spot prices, is a problem of 'missing money', that is, the inability of power plants to collect positive net revenues through the participation in competitive spot markets that would guarantee a fair return on investment. The spot prices, in their view, would not

[7] See previous paragraph.
[8] We refer to a scenario in which the development of RES occurs without storage resources.
[9] That holds true to the extent that the wholesale market prices reflect the short term marginal cost of the marginal generation capacity needed to balance supply and demand. During scarcity events prices should be as high as the Value of Lost Load.
[10] P. Cramton e S. Stoft, The Convergence of market designs for adequate generating capacity, 2006; P.L. Joskow, Competitive electricity markets and investment in new generating capacity, in D. Helm The New Energy Paradigm, Oxford University Press, 2007; P.L. Joskow, Capacity Payments in imperfectly competitive electricity markets, Utilities Policy, 2008; P.L. Joskow e J. Tirole, Reliability in competitive electricity markets, in Rand Journal of Economics.

produce the long-term price expectations that would encourage adequate investments, given that, contrary to what is assumed at a theoretical level, the spot prices under stress conditions do not increase sufficiently to provide a correct scarcity signal. The main causes of failures of energy-only markets based on scarcity pricing stem from: i) market price caps; ii) the ways in which the SOs manage emergencies, by resorting to 'off-market actions' which ultimately do not allow the price to reflect the real scarcity situation (e.g. voltage reduction).

However, even if these market failures, due to the regulation and/or the behavior of the SO, were overcome, and consequently there was no problem of 'missing revenues', it is difficult to deny that in the electricity market there is a very high level of risk. This is primarily due to the intrinsic difficulties of the 'energy only' markets of promoting the investments needed to guarantee security and adequacy standards. Indeed, the expected growth in RES penetration of renewables can only increase this risk, making even more urgent the need to combine traditional spot wholesale markets with long-term contractual instruments in order to promote the investments necessary for decarbonisation.

1.1 Focus on the need for forward contracts in order to develop storages and RES

In order to accommodate RES penetration levels consistent with the decarbonisation objectives, electrical systems will possibly have to build considerable storage capacity in the coming years.
In fact, a high penetration of RES is achievable and sustainable only in the presence of adequate storage capacity, both from an economic and system security point of view. This capacity is needed for:

- reducing the RES over-generation, when storing the "excess" RES production is the most efficient solution in order to achieve the decarbonization target;
- contributing to the adequacy and the security of the system, providing ancillary services (voltage, frequency, inertia regulation) featuring low/zero technical minimums (during high RES hours) and fast activation and quick response time to load variations (i.e. to cover evening ramps).

Investments in storage technology, which, as illustrated above, are necessary to respond to critical issues induced by the introduction of high levels of RES in the electricity production mix, depend on the growth of the renewable generation fleet.

The recent emphasis on storage in the United States' electricity industry is a clear example of this. Many states, at least in the last decade, have focused essentially on promoting the development of solar and wind energy and have adopted a variety of support policies. More recently the development of storage has been promoted, since it has become clear that, given the intrinsic characteristics of RES, the challenges of penetration of these sources cannot be overcome except by integrating adequate storage resources in the generation portfolio. In many cases, individual States have followed the provisions of the Federal Energy Regulatory Commission, and asked SOs to adopt rules to allow storage to compete with other generation resources 'on a level playing field'. The individual states have simply extended subsidy mechanisms to storage technologies, directly or indirectly[11], as a way of promoting the development of renewables.

The European community in general and Italy, in particular, are just now starting to consider the need for some form of system intervention to ensure adequate investments in storage capacity.

[11] In the United States, several tax subsidies have been introduced at federal level to support RES development. Many states have provided for additional subsidies, both explicit (essentially tax benefits) and implicit. The latter, see the case of California, consist in laying down obligations on energy sellers to guarantee coverage of their sales with a predefined share of renewable energy.

In fact, as already mentioned, the quest for storage technologies and the pursuit of opportunities for price arbitrage between the different periods of the day and/or between the different days, can provide the system with both peak capacity to achieve adequacy standards and regulation and modulation services. Storage resources can therefore access different sources of income, such as:

a) the sale to other market players (in particular, owners of RES) of hedging instruments with respect to the volatility of prices in the market or, similarly, of products that allow a shift of electricity production over time.
b) arbitrage activities in the energy markets
c) the sale to the System Operator of services (regulation and reserve) within the ancillary markets, and
d) participation in capacity markets, if any.

Except for the last item, all the other means of income are typified by a high degree of uncertainty. In particular, the first two are strongly influenced by the actual RES and network developments[12]; the third depends on the results of a market - that of ancillary services - exposed to the trend of multiple variables that interact with each other in a complex way on the basis of algorithms defined by the SO.
Given the above, it is clear that the level of risk associated with merchant investments is very high, since these are resources: i) characterised by high fixed costs; and above all ii) whose value depends on exogenous variables that are not predictable by the investor. In particular, storage revenues are ultimately a function of the level of penetration of renewables and of grid developments; without considering that (a good part of) their margins depend on the provision of ancillary services for which there is no predictability of the forward value, nor the possibility of hedging, unless the SO provides guarantees through forward contracts.

Additionally, it must be considered that, although storage may be the most economical manner of achieving the challenging targets of RES penetration, market prices alone cannot support merchant investment for these resources, given that they are not able to factor in the effect of externalities needed to comply with the decarbonisation objectives[13].

Therefore, since the type, quantity and location of investment in storage resources are risky and strongly affected by investment decisions in both RES and network infrastructures, regulation must fulfill two requirements to promote efficient development of the electricity system:

1) define mechanisms that, through appropriate forward contractual arrangements, ensure adequate availability of these resources;
2) achieve strong coordination between developments in renewables, storage and network infrastructures.

[12] To date, in capacity constraint systems, the growing penetration of RES is increasing price volatility and widening the differentials between hours of the day and / or between different days. The problem is that this price volatility, necessary to support investments in storage, depends on renewables and storage development trajectory. In fact, the following interdependence applies: the storage investments are repaid only with a high penetration of renewables, while a high penetration of renewables is sustainable, both from the economic and system-security point of view, only in the presence of adequate storage resources. It follows that the remuneration (on the market) of the investments in storage is strongly conditioned by the actual developments in RES and vice versa. In other words, the remuneration of storage and RES is guaranteed only by a complex dynamic balance between these two technologies.
[13] Consider that, although the price in over-generation hours may be low (even zero), the price in hours where value is set by traditional thermoelectric plants (hours in which stored energy must be shifted) may still not be high enough to repay the fixed costs of storage.

Moreover, with a view to carrying out the decarbonisation process efficiently, it is also necessary to review the current support mechanisms for RES investments that present various critical aspects.

3. An overview of the overall design: rationales and mechanisms proposed

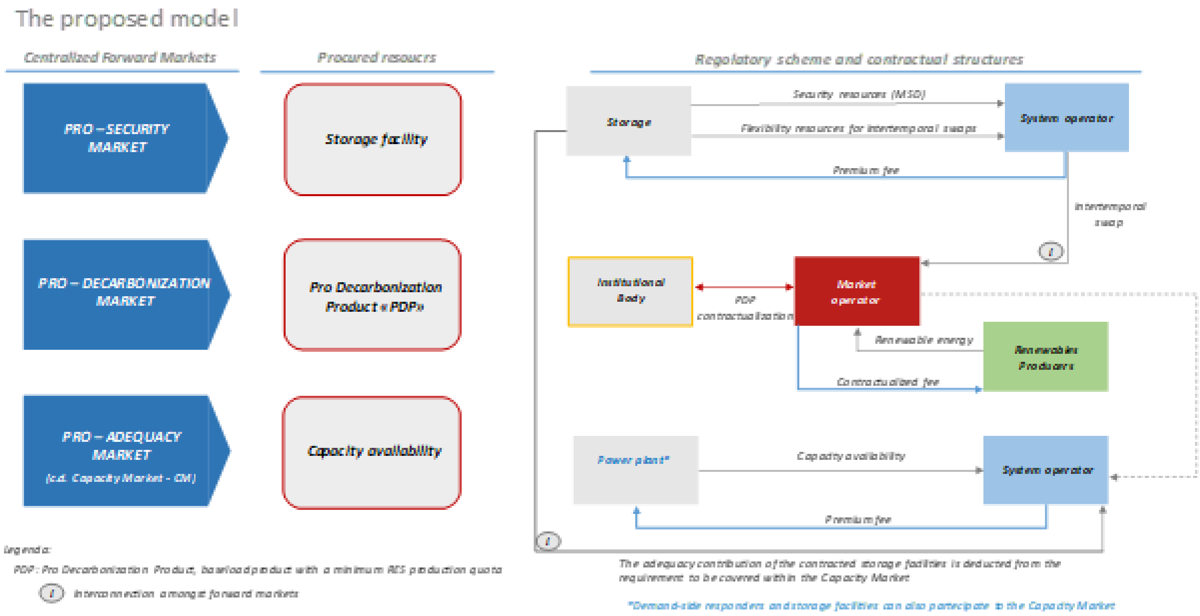
As previously highlighted, the decarbonisation objectives require a high degree of coordinated investment planning. This does not mean renouncing market mechanisms, rather, designing an efficient system that combines the current instruments of 'competition in the market' with suitable forward market mechanisms. More precisely, the model considers that the system guarantees the availability of a 'minimum necessary' quantity [14] of resources to be procured through competitive forward mechanisms; the selected resources should be contracted with schemes that allow for their full integration into the market. This means that these resources compete (with each other and with the other merchant resources available) in the spot markets - in compliance with the long-term contractual commitments assumed - and are exposed, at least at the margin, to their dynamics (price, risk/cost of imbalance, etc.).

To date, there are already centralised forward contract mechanisms in the Italian system, as well as in other European systems, in which counterparties are selected on the basis of competitive auctions. We refer to contracts used to promote the construction of RES capacity and to 'capacity contracts' to ensure the adequacy of the system (so-called Capacity Market). To the extent that the availability of additional resources (primarily storage) is needed, the introduction of new mechanisms and the opportunity to innovate existing ones are envisaged.

Before going into more detail on the specific instruments, we provide an overview of the proposed design, in order to clarify the rationale of the model and the interaction between its different parts. The value of the proposal, in fact, not only stems from the structure of the single mechanism, but also from how the linkages between the different tools were designed. In this regard the proposal objective is to ensure that both sides - market players, in making their merchant investment decisions, and System Operators, in expressing the demand for resources to be procured centrally - take full account of the externalities produced by the contracted resource.

The model is built on a sequence of three forward markets, whose linchpin is identified in the procurement of resources functional to the security of the system.

[14] This represents the minimum quantity of resources needed to achieve the objectives of: (i) renewables penetration and, at the same time; (ii) ensuring the security and adequacy of the electricity system. That minimum quantity of resources should be defined comparing multiple scenarios, applying a minimum regret criterium and taking into proper account: i) the amount of resources that will be probably developed at distribution level (to tackle security issues at distribution level) and ii) the merchant ones.



The sequence is chosen in order to minimise the inefficiencies of having three separate markets/tools instead of one that would require too complex algorithms. Therefore, i) the sequence of the markets should commence with the market in which the different kind of selectable resources have, among them, almost the same ability to satisfy the 'specific' needs of the subsequent markets[15]; put it in other words, the sequence should start with the market that minimizes the inefficiencies due to not considering the externalities induced into the subsequent markets by different mix of resources selected in that first market; ii) the resources procured in each market have to be properly taken into account in determining the demand of the following markets.

The three interconnected markets are:

1) Pro-Security Forward Market: The SO defines the minimum quantity and the mix of resources (including the development of network assets), also taking into account the expected development of resources connected to medium and low voltage networks, that should be available in the future to ensure the security of the system, reducing the risk that RES production needed to efficiently achieve the penetration target is curtailed[16]. Once the minimum set of resources has been identified, the SO proceeds to procure them through competitive procedures. The selected counterparties assume the obligation to make the contracted resources available in the spot markets under predefined conditions. Among the pro-security resources, the role of storage is particularly important, as it is fundamental to allow the shift of RES production over time. With regard to these resources, the proposed design envisages that: on one side, the SO covers the entire investments through the forward contract; on the other side, it takes on the risk of value obtainable from the energy markets (this mechanism differs from the situation where storage operators sell to the SO, through forward

[15] This applies in particular to storage resources. Therefore, in describing the first market, we will limit ourselves to considering how to contract these resources.

[16] The SO should define the need for pro-security resources to be procured, in a conservative way (minimum regret criteria), reducing the risk that RES production needed to achieve the penetration target is curtailed. In this evaluation, the SO compares different least-cost scenarios, characterized by different combinations of RES, network developments, storages and other pro-security resources.

contract, solely ancillary services[17]: indeed, in this second option, storage resources are still exposed to market risk, as their investment costs are only partially covered). To the extent that the investment is already paid for (by the SO), this arrangement leads to two implications for the design of the model: i) the storage operator must settle with the SO the net value that it would obtain in the energy markets if it offered as requested by the SO itself (like in a virtual tolling contract); ii) the adequacy contribution of the contracted storage facilities is deducted from the demand for adequacy resources to be procured within the Capacity Market, as these resources are already available.

2) Pro-Decarbonisation Forward Market: In the proposed model, this market replaces the current support mechanism for renewables, which should remain operational only for those technologies which, for example, due to their innovative and/or dimensional characteristics, cannot be considered in market parity. Contrary to today's arrangements, the proposed mechanism does not intend to support the development of RES by forward contracts directly related to specific plants. Rather, it is expected that the entity responsible for the decarbonisation objectives purchases from the market multi-year products (hereinafter called Pro Decarbonisation Product - PDP) which, in return, commit the counterparty to:

    a. settle with the system the difference between the arithmetic average of market prices (baseload products) and the strike price, defined as a result of the pro-decarbonisation market's auction;
    b. generate, from renewable plants that comply with given criteria, an amount of energy that meet a predefined minimum share of the energy underlying the subscribed PDPs, on an annual basis.

   In order to allow the market players who signed PDP contracts to manage the risk linked to the difference between the RES' production profile and the contractual commitment assumed (e.g: baseload profile), the system gives them access to some intertemporal swap products that the SO can "build" utilizing the storage contracted capacity, after deducting what is needed for ancillary services.
   Finally, to minimise market player transaction costs, it could be also envisaged that the PDP be associated with a commitment to provide adequacy resources within the Capacity Market, valued at a predefined premium. The quantity of PDPs to be procured and the minimum production quota from RES should be determined so to achieve two objectives:

    - ensure that, through the PDPs, market players commit themselves to produce a minimum amount of RES energy, leaving the market - possibly through 'PPAs' - to

[17] The choice here proposed, not only to simply procure ancillary services but to contract the whole storage capacity needed to manage the RES over-generation issue, is coherent with the fact that the storage resources are functional to manage both: i) the possible over-generation problems that can be foreseen in advance and, therefore, preferably managed in the energy markets; ii) and the issues that arise due to the fluctuation of RES production in real time. Therefore, should the SO decide to contract only ancillary services on a forward basis, a major problem would be the sizing of the resources to be purchased. In fact:
- if the sizing is based on the capacity needed to manage RES production variability close to real time, the system could lack enough resources to manage the cases in which the over-generation (the quota that has to be stored to achieve the penetration target) can be forecasted and more efficiently managed in energy markets;
- on the other hand, if the sizing is based on the whole capacity needed to efficiently manage the over-generation, the energy markets outcomes could be sub-optimal, due to storage operators being incentivised to preserve their storage resources for the ancillary services market.

produce additional quantities of renewable energy, facilitated by a less risky environment (due to the higher storage capacity in place, which would reduce price volatility);

- lead PDP contract holders to develop an appropriate mix of RES and additional storage resources in order to hedge the financial exposure underlying the PDP commitment; in fact, a greater mandated share of production by RES in the PDP promotes the development of additional storage resources (given the amount of swap products assigned).

3) Pro-adequacy forward market: this market, already launched in Italy with the so-called Capacity Market, is not specifically investigated. It is mentioned at this point only to highlight the linkages with the other two markets, in order to avoid double counting at the expense of the system.

The model described above at a macro level has been designed to pursue the following objectives:

1. ensure the availability of a minimum quantity of resources functional to achieve – preserving the security and the adequacy of the system - the decarbonisation objectives, by efficiently allocating risks between the system and the market players, in order to contain the overall costs of the decarbonisation process. According to this logic, it is the system that assumes the risk of the actual need for forward resources (both in terms of over-generation and intermittency management) and the consequent investments;
2. create an 'environment' that, leveraging on available assets, is capable of accommodating merchant initiatives for the development of renewables and storage capacity, for example via PPAs; in other words, centralised forward contracts should not substitute for merchant initiatives, but should be limited to what is strictly necessary to encourage their development;
3. achieve an efficient coordination between the various forward contracting mechanisms and with respect to market initiatives, so as to maximise synergies and allow a correct exploitation of the interrelated externalities;
4. ensure full compatibility with the functioning of the spot markets so that they can express correct signals on the real value of resources in order to maximise short-term (productive and allocative) efficiency.

Below is a more detailed description of the design of the single elements that form the model.

4. Pro-security forward market: rationale and mechanism for storage resources forward contracting

As illustrated above, the development of storage is associated with an even higher level of risk (i. as a result of the significant degree of capital intensity; ii. due to the storage value being dependent on RES investments and network developments; iii. finally, given that (a relevant) part of the margins depends on the supply of dispatching services) compared to the existing extremely high risk inherent in investments in the electricity sector.
The risk of under investment, and therefore of not having adequate storage capacity necessary to meet the ambitious targets for the development of renewables, requires - through centralised forward contractual mechanisms - the availability of an adequate amount of these resources.

Given the need for contracting these resources in advance, the question arises whether:

a) it is sufficient for the system to contract storage resources solely to provide ancillary services, therefore leaving to the plant the task (and the risk) of being able to obtain from the spot markets the remaining cash flow to recover investment costs; or,

b) opting for an all-inclusive, centralised contracting solution in which the system covers the entire costs and takes on the market risk coming from the energy markets.

This second option appears preferable for at least two reasons: i) it is ultimately the system that decides not only the network upgrades and expansions, but also the extent and speed of penetration of RES in the market[18]; this in turn affects the value of storage in energy markets (the system itself is therefore the entity best positioned to estimate the value of these storage resources); ii) centralised forward procurement allows for the efficient allocation of intertemporal storage/swap products that: a) are standardised, and therefore negotiable; and b) reduces performance risk (e.g. unavailability) linked to the individual plant through the pooling of resources.

Based on the abovementioned premises, the regulatory framework governing the centralised forward contracting of storage systems should be constructed in order to pursue the following objectives:

- allow storage capacity investors (including existing ones on a voluntary basis) to fully recover investment costs through the auction premiums awarded in the pro-security market auctions;
- ensure SO neutrality with respect to the operations of these resources on the energy markets;
- uphold simultaneously market player incentives to promote the efficient plant dispatching on the energy markets, while limiting the uncertainty of the additional margins obtainable.

The first objective is achieved by the 'all-inclusive' contract solution.
In order to achieve the second one, it is necessary that the bidding strategy of storage resources in the energy markets, be determined by third parties, and not by the SO (in fact this would require economic responsibility, with evident repercussions on its third party nature with respect to participation in the markets).

As long as it has been decided to minimise the risk borne by the storage operators on the value of their assets, it should not be left to them to 'freely' decide how to bid in energy markets. Therefore, to reach the third objective, the bidding strategy should be implemented by storage operators, that should be made economically responsible if they deviate from the bidding strategies defined by the third parties (market players).

In defining the quantities of resources, in particular storage, to be procured centrally, the SO should deduct, from the 'expected optimal requirement' calculated on the basis of its forecast of evolution of the relevant variables at the zonal level[19], the resources (e.g. storages and DSR) that:

- are forecast to be developed at a local level (distribution network) as contracted by distributors to effectively manage network/security constraints connected with a greater penetration of distributed renewable resources;
- should be developed directly by market players on a merchant basis; leaving some room to market forces to define the most efficient solutions, to better take into account the different mix of renewables they want to develop. On the other hand, the stimulus for the development of these additional storage resources should also come from the subscription of the PDPs.

As already mentioned, this requires the SO to determine storage needs conservatively, considering minimum objectives, such as, for example, the minimum quality of service levels.

The regulatory scheme that is proposed in this paper is divided into two distinct contractual structures: i) one between the SO and the storage system investors (the so-called storage contract); and ii) another

[18] Through the forward contracting mechanisms of these resources.
[19] See footnote #16

between the SO[20] and the market players to which the intertemporal swaps are allocated (the so-called intertemporal swap contract).

4.1 Focus on the storage contract

The storage contract is a multi-year forward contract between the SO and the operator of storage facilities that meet the SO's need to guarantee the supply of dispatching resources (in MSD – Dispatching Services Market), essential for the safe management of the electricity system. It would be based on the contractual scheme envisaged:

- the SO pays an annual premium (to cover Regulated Asset Based remuneration, amortisation and operating costs) on the basis of final storage auction parameters;
- storage system operators agree to: i) be available for dispatching purposes; ii) settle energy exchanges in energy markets that derive from the orders enacted by the SO[21], within the limits of contractual flexibility and subject to the constraints defined by the SO itself for the security of the system.

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With respect to the operation of the storage system, ahead of relevant energy market gate closures, the SO sends to the storage operator two different types of orders:

a. commercial schedules that define a 'theoretical' programme on the energy markets. This programme is defined by the SO so as to reflect the requests received from market players (when executing the swap contracts);
b. binding dispatch orders setting the boundaries that the storage operator has to respect in order to preserve enough resources for the MSD in compliance with the storage capability as set in the contract (boundaries defined both in terms of minimum/maximum energy that has to be stored and of minimum/maximum net production level); the SO should set those constraints in a flexible manner so as not to jeopardise the efficient use of the storage[22] with the possibility of: i) being differentiated for the different time periods and ii) being relaxed if the System Operator deems this compatible with the operational needs in MSD[23].

Therefore, the operator of the storage system will define its physical schedules subject to the physical constraints (orders under b.), at the same time being economically responsible for the programmes required under a. This means that it will treat the revenues and costs associated with the scheduling actually chosen, but it will have to settle with the SO the economic value that would have been derived if it had executed the 'theoretical' programme requested in the energy markets.
On the other hand, as regards the participation of the storage systems on the Dispatching Services Market:

- the operator of the storage system must offer the upward (downward) capacities in compliance with the maximum (upward) and minimum (downward) price values established in the contract with the SO;

[20] For the sake of simplicity, a direct relationship is assumed between the System Operator and the market players holding the intertemporal swaps.
[21] These energy exchanges are requested by the System Operator in execution of the swap contracts allocated to market players.
[22] Excessively stringent limits would unduly compress the number of intertemporal swaps that can be assigned and therefore increase, *ceteris paribus*, the burden to the system.
[23] Flexibilities made available by relaxing contractual constraints could be sold on a spot basis.

- the SO defines the physical storage schedules and, having paid a premium in line with the investment costs, settles at the prices offered by the storage operators only the net balance of the movements requested in the MSD on each day[24].

Finally, with the goal of extracting the maximum value from the storage contracts employed by the system, it is expected that the adequacy contribution of said facilities will be deducted from the requirement to be covered within the Capacity Market, since these resources are already available. These quantities are subtracted when determining the demand curve in the Capacity Market, thus reducing the system's economic burden; the system saves the corresponding premiums.

4.2 Focus on the intertemporal swap contract

The market design here proposed envisages that the storage systems contracted by the SO are used, in addition to managing the electricity system safely, to provide hedging contracts to manage the volatility and unpredictability of market prices. These intertemporal swap contracts are therefore extremely valuable hedging instruments when managing the volatility of RES generation.

First of all, this solution responds to the need of transferring to market players optional contracts for the (virtual) energy shifts[25]. Given that the value of storage resources is strictly linked to the degree of RES penetration (and vice versa), this instrument could support investments in RES resources.

The SO converts the additional flexibility[26] provided by the storage systems contracted in the security market into intertemporal swap standard products, which are primarily assigned to the parties awarded the PDP contracts. These options allow these parties to change the economic value of their electricity, by shifting it over time and thus obtaining the net value (positive or negative) resulting from that shift[27]. More precisely, with a predefined notice ahead of the relevant energy market gate closure, here is how it would work:

- the option holder can send the virtual storage utilisation schedules to the SO, within the technical parameters defined in the contract;
- the SO: i) on the basis of predefined algorithms, transmits the requests received to the operators of the storage facilities; ii) pays to, or has the right to be paid by, the market player the value of the requested transactions. In economic terms, the SO still maintains a neutral position as it receives (pays) the same amount it pays to (receives from) the operators of the storage systems.

The regulatory framework governing intertemporal swap contracts therefore considers that the relationship between the storage system and the beneficiaries of the swap option is intermediated by the SO, so as to create, at zonal level[28], a sort of 'virtual' storage. This is a key feature of the model, both to optimise storage use and to ensure that the swap products sold to the subscribers of PDPs have the same value, at zonal level. It therefore requires standardisation and an intermediation of the operational management (always at zonal level).

[24] The delta must be quantified using the standard transformation loss factor, provided for in the contract.
The delta must be quantified using the standard transformation loss factor, provided for in the contract.
production / storage schedules, avoiding discretionary decisions of the SO (which must maintain its neutrality) and of the storage system operator (whose risk profile linked to the participation in energy markets is minimised by the scheme proposed).

[26] This flexibility is additional with respect to resources strictly needed for ancillary services but is coherent with the sizing of procured resources, taking into account the over-generation issue (as illustrated in footnote 15).

[27] Clearly the standard loss coefficients apply to the energy shift required.

[28] Within the limits in which there is transport capacity available between different market zones, virtual storage could also have a macro-zonal dimension, grouping the storage capacity located in a set of zones.

5. Pro-Decarbonisation forward market

The development of renewable sources is now promoted through long-term support mechanisms (so-called two-way Contracts for Differences) which ultimately provide for the payment to the plant's owner (winner of the auction) of a fixed fee, independent of the market price, for the energy that has been produced and fed into the network (EUR/kWh)[29]. It follows that today the operator is only incentivised to maximise the energy actually produced by the plant.
In particular: i) production decisions can be taken independently of the energy market prices and, ii) the energy produced is offered on spot markets at prices that do not necessarily reflect the variable costs (however low) of the plant; since the goal is to produce in any event[30].

The failure of the current mechanisms to promote full integration of RES resources into the market is therefore evident. These arrangements neither provide a correct signal to investments in terms of type and location, nor do they induce the owner to maximise the value of production (production decisions are taken independently of the energy market price).

To overcome the critical issues, firstly it is necessary to modify the structure of the contractual payoffs with the dual objective of:

1) ensuring the selection of resources with greater added value for the system (not only in terms of greater RES electricity volumes produced but also in terms of value for the system)[31]. This implies that investments - such as the location of the plants – are made in accordance with the expected network upgrades and storage system roll outs;
2) putting in place an incentive mechanism that supports the integration of RES resources into the market, with a cost-reflective bidding.

This requires that the contractual payoff refers to a standardised theoretical production profile and that the different locational value of the energy produced is appropriately considered[32]. Making this change primarily means going beyond the current design mechanism in which the contracted resource is the specific plant. Decoupling the incentives from the single plant and the related specific production allows: 1) the direct empowerment of the market to fulfill its ultimate objective, i.e. the achievement of minimum renewable electricity production targets; 2) that this objective can also be achieved through a portfolio of plants, provided they respect predefined characteristics.

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[29] On the other hand, feed in premium schemes (on top of market price), although they have the undoubted advantage of exposing the generator to price signals, with all the benefits deriving for the system, are characterised by a high risk level borne by the producer.

[30] Consider that these schemes often maintain an incentive to produce even with negative market prices, while the plants still have positive, albeit limited, variable costs.

[31] See also P. Joskow, *Comparing the costs of intermittent and dispatchable electricity generation technologies*, American Economic Review, Papers & Proceedings, 2011

[32] The proposed PDP design, where the products are localized at zonal level and have the same baseload profile, assumes that combining different types of RES located in different zones has limited value and/or it's not feasible for technical/political constraints.
If it were otherwise (see P. Joskow, *Transmission Capacity is needed to decarbonize the electricity sector efficiently*, Joule 2019), alternative solutions could be implemented: 1) allocating (also) PDPs with differentiated contractual profiles (to reflect the local RES expected production profile), under the constraint that the sum of the purchased PDPs "builds" the desired cumulative profile, given the inter-zonal transmission constraints (more centralized option); 2) maintaining the baseload profile of the PDPs and make available to operators transmission rights between zones with time profiles that reflect the production profiles of the RES that are assumed to be most profitable to be developed in different areas (more decentralized option).

Moreover, such a framework requires to adequately define the PDP standard production profile. Choosing the standard profile poses two problems that must be reconciled: firstly, the need to identify a profile that guarantees technological neutrality, so as to leave to the market the choice of the technology mix to be used[33]; secondly, the need to minimise the risk to which market players would be exposed if they were unable to efficiently replicate the profile to which they committed themselves.

To address these two potentially conflicting needs (standardisation of product versus minimisation of the risk borne by the market player), the proposed model envisages that: 1) the profile of the Pro Decarbonisation Product (the PDP), is standard and (most probably) a baseload[34], with a mandatory minimum RES production quota; 2) preferential access to predefined quantities of intertemporal swap products (based on the swap contract referred to in the previous paragraph) is given to the operators awarded the PDP contract.

In this way, although the introduction of a PDP baseload product increases the risk borne by the market player relative to the current support scheme, such risk is mitigated by two corrective measures.
First of all, the commitment on RES quota is only for a share (however potentially high) of the energy underlying the contractual PDPs; a commitment, which, moreover, can be fulfilled through a set of resources that meets predefined criteria. Therefore, the operator benefits from portfolio effects (in addition to being able to possibly acquire ad hoc certificates[35] from third parties). Furthermore, the fact that the contractual obligation is defined as an annual quota lessens the RES producer incentive to inject electricity in a specific hour, especially when market prices are below marginal costs. To further reduce this incentive (producing even when prices are lower than marginal costs), the mechanism could provide for the possibility of offsetting lower renewable injections in one year with higher inputs in subsequent years[36].

Secondly, the model envisages that PDP counterparts would be granted preferential access to intertemporal swap products that maximise the value of the energy produced.

Turning to the description of the Pro-Decarbonisation Forward Market, it is proposed that the system should, in the first place, define in a consistent way: 1) the quantity of PDP to be supplied and 2) the minimum percentage of RES production for each MWh of PDP contracted. These two parameters constitute two levers through which the system can define: 1) on the one hand, the balance between the resources promoted through the PDP and those developed under different mechanisms (e.g. PPA) or fully merchant; 2) on the other hand, the amount of storage capacity (additional to those supplied in the pro-security market) whose investment is supported through the PDPs.
In fact, by reducing the amount of PDP supplied by the system and, correspondingly, increasing the RES quotas in PDPs, a greater space will be left for the development of merchants' RES. Moreover, a more favorable environment will be created thanks to the greater expected availability of storage resources that the PDP counterparties are implicitly incentivised to realise.

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[33] In this regard, it is stressed that the typical production of wind and photovoltaic technologies present uncorrelated profiles: this is true both on an hourly and a daily basis as well as on a seasonal basis (with wind having higher load factor in winter, photovoltaic, in summer); in principle this permits possible optimisation for market players with an 'efficient' portfolio of RES technologies.

[34] Defining a product, whose expected value is easier to estimate has positive effects also with reference to the quantification of guarantees.

[35] The multi-year nature of the PDP overcomes the critical issues that characterised the green certificates mechanism: a scheme that was not referred to a specific power plant, but that did not give guarantees on the value of production in the long term, except through the introduction of administered caps and floors.

[36] Since the proposed mechanism does not provide for administered floors for energy produced from renewable sources (an aspect that characterises the green certificate scheme to provide long-term guarantees to investors in renewables), production decisions reflect (almost) exclusively the margin obtainable on spot markets.

Once the above parameters have been determined, the entity in charge of implementing the decarbonisation objectives procures long-term PDP contracts (e.g. for the duration of 15 years) for the supply from the market of the Pro Decarbonisation Products[37]. Market players, selected through competitive descending auctions with demand defined at zonal level (taking however into account the transport capacity among zones)[38], commit for predefined quantities of energy (MWh/year) to:

1) settle with the system, based on yearly periods, the difference between the contract price and the arithmetic average of the wholesale market prices (for the relevant area);
2) inject in the system during each relevant year a predetermined amount of RES generation proportional to the contracted PDP volumes This amount can be produced either by a portfolio of resources under market player control or through an equivalent amount of certificates issued by Third Parties (in this case appropriate vintage rules would apply). This obligation could also be met by relying on existing plants if they are not yet benefiting from other incentive schemes (or excluded due to specific provisions).

In order to allow PDP holders priority access to intertemporal swap products, two alternative mechanisms can be put forward.
Under the first mechanism, one that would be simpler to implement, the market player receives a predefined quantity of intertemporal swaps for each contracted PDP unit[39]; where intertemporal swaps refer to the same zone of contracted PDP. In this way, market participants would discount the value attributed to intertemporal swaps in their offers for the subscription of PDPs. However, the trading of the intertemporal swap products in a specific regulated market should be allowed.
Under the second mechanism, which makes it possible to achieve greater efficiencies but at the expense of ease of implementation, both PDPs and intertemporal swaps are assigned at the same time. In this way, market participants would be called upon to submit three offers: 1) for PDPs with contextual assignment of intertemporal swaps; 2) for PDPs without contextual assignment of intertemporal swaps; 3) for intertemporal swaps. With appropriate algorithms it would therefore be possible to identify the solution that efficiently allocates the products through system welfare maximisation.
In both cases, the amount of intertemporal swaps that can be allocated in each zone adequately takes into account the transmission capacity between the zones.

In the event of non-compliance with the prescribed RES injection volumes (which meet specific requirements), and without prejudice to yearly built-in flexibilities, it could be possible to apply a penalty, possibly linked to the results of the auctions for the support of innovative renewable energy production technologies.
The amount of guarantees that market players would be required to pay could take place on the basis of mechanisms similar to those proposed in ARERA's consultation document n.27 of 2008, containing ‘Guidelines on measures aimed at facilitating the negotiation of long-term coverage in the electricity market’, to which reference is made.

[37] Instead of a centralised supply model of the PDPs, a final consumer or supplier obligation to purchase a predefined quantity of the PDPs could be envisaged (based on consumption in each year).
[38] Similar to what was done for the Capacity Market.
[39] The products to be made available to contracting parties should also include Power-to-X transformation products (gas and / or hydrogen), where the related plants are subject to centralised forward contracting and / or tariff regulation. These products would allow the owner to transform the renewable energy produced in a given period into the ‘fuel’ to be used for the production of electricity in subsequent periods. These products, even if not necessarily combined with gas storage (in fact consider the low volatility of the gas price, in particular over short time horizons), allow possible replication of the effects of storage.