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Balancing Efficiency, Equity, and Security

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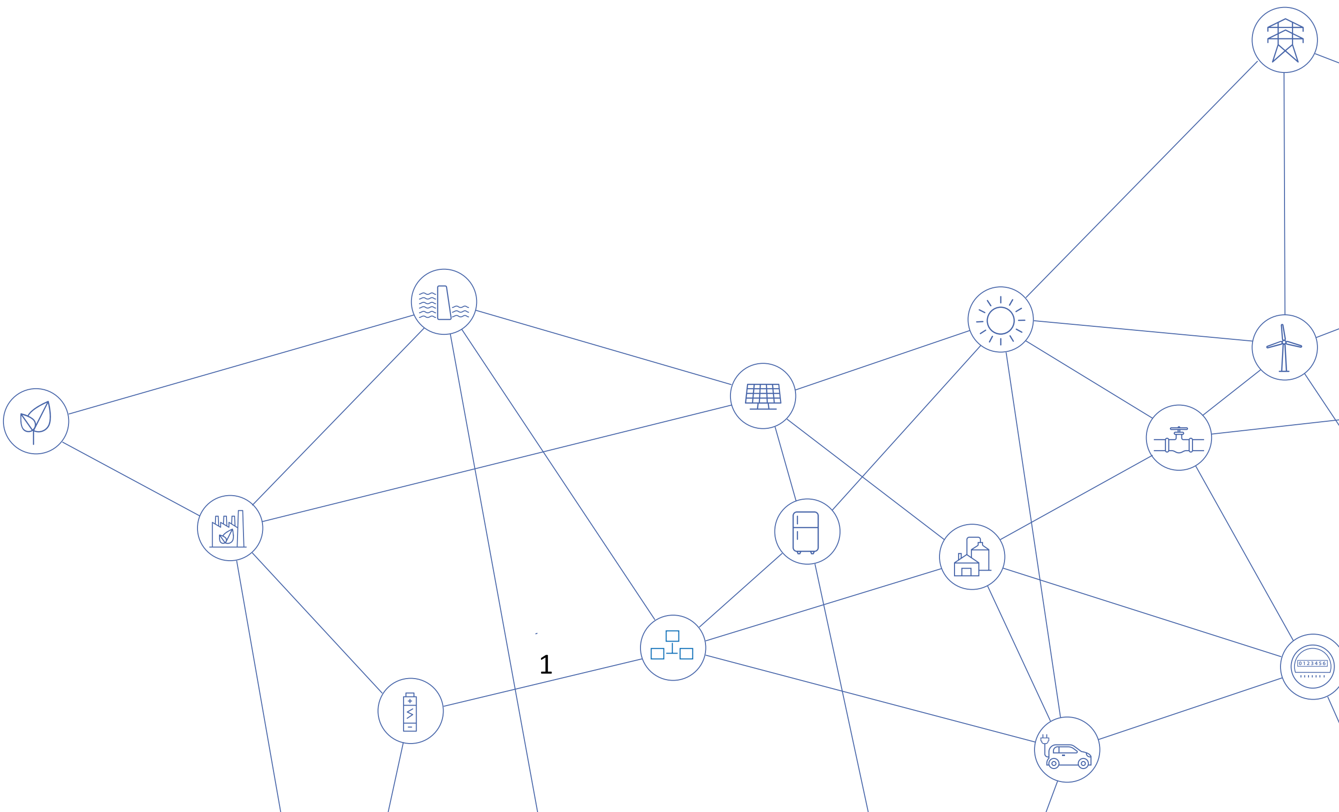

Electricity Markets in Transition and Crisis: Balancing Efficiency, Equity, and Security

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Abstract

Two electricity market crises following the lifting of post-Covid restrictions in 2021 and the natural gas supply interruptions in 2022, challenged the functioning of the EU electricity market and its design. This paper argues that the market design was already ripe for an overhaul as the efficient market paradigm has gradually given way to as instrument of cost-effective attainment of green targets and balancing of the elements of energy trilemma. We discuss the linkages between the long-term and short-term markets. While policy interventions to alleviate short-term affordability are important, they cannot constraint the long-term sustainability and security of supply. Short-term electricity markets have, technically, worked according to design. However, the distributional implications of them call for revisiting how resources are allocated to and operate in the market. We revisit several dimensions of market design with a view to the recent calls and to review and overhaul them such as windfall tax, contract for differences, market decoupling etc.

Key words: Electricity, market design, energy markets, natural gas, energy reform, affordability, security of supply, sustainability

JEL classifications: D2, D3, D6, L1, L5

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1. Introduction

Since 2021, the European Union electricity markets have experienced two distinct shocks. The first was a positive demand shock in 2021 after the relaxation of Corona restrictions in some Member Countries (Lyu et al., 2022). The second was the negative supply shock of natural gas and price of gas power in 2022. The severity of both events can be explained by the low short-term price-elasticity of electricity demand and supply. As is often the case, many crises are caused by the combination of known risks. The effects of both events were exacerbated by other supply-side shocks, such as low levels of wind, low water levels in reservoirs, high coal prices[1], and extended outages in nuclear plants in parts of Europe. The cumulative effect of these factors amounted to a perfect storm in the electricity markets.

After the post-Corona 2021 shock, there were calls for reforming the electricity market design by some Member Countries to address the social and economic concerns emanating from high electricity prices.[2] On 25 October 2021, some member countries declared confidence in the energy markets stating that the market design was not the cause of the crisis (Joint Statement, 2021).[3] However, the market design had not prevented the shock either. This is not to suggest that electricity markets no longer work. Rather, it invites to revisit the design and outcomes of the markets in an already evolved context and continuous technological progress, mass connection of renewables, and a reorientated energy policy. Indeed, even prior to the shocks, the electricity market design was ripe for an overhaul.[4]

Despite the shocks, short-term electricity markets have ensured the security of supply, but in exchange for very high prices, also affecting the affordability. This process has been amplified when the hedge positions of retailers in the long-term markets were not enough. In some countries, many suppliers have also gone out of business as in the UK.[5] This has resulted again in calls for reforming the electricity markets, also considering redistributive mechanisms for windfall profits, or instruments such as higher demand flexibility or proactive networks integrating more renewables. It is also imperative to balance the three objectives of the energy trilemma: sustainability, supply security, affordability.

[1] https://tradingeconomics.com/commodity/coal
[2] See, e.g., Reuters (2021).
[3] 2021-10-25-Energy-Prices-in-the-EU-Joint-Statement-AT-DE-DK-EE-FI-IE-LU-LV-NL.pdf (politico.eu)
[4] We distinguish between short-term and long-term markets. The former corresponds to the current day-ahead wholesale market, and the latter to the current forward over the counter markets. Intraday electricity markets and frequency ancillary services have important particularities and are out the scope of this paper.
[5] https://www.ofgem.gov.uk/information-consumers/energy-advice-households/what-happens-if-your-energy-supplier-goes-bust

This paper revisits the role, design, and policy aspects of the wholesale electricity markets in the EU in the context of recent shocks and future changes. It examines the changing market context and design challenges facing the electricity markets, also discussing how these instruments affect the energy trilemma pillars. Section 2 introduces some characteristics of electricity as a commodity and system. Section 3 discusses potential changes in the own electricity market design. Section 4 analyses instruments not directly related to the market design, but with potential impact on market performance. Section 5 considers potential redistributive instruments. Finally, section 6 presents the conclusions and some policy recommendations.

2. Economic fundamentals of power systems

2.1. Electricity as a special commodity

Electricity has unique characteristics among the important traded commodities (oil, grain, gold, copper, beef, or natural gas): (i) The demand for electricity is relatively inelastic and follows seasonal patterns. (ii) The supply is made up of different technologies. Renewable energy output is linked to variable and random weather conditions, such as wind and sun, while thermal technologies can be dispatched on request.[6] (iii) The electricity generated must match the demand at each moment.

An imbalance between generation and consumption can risk the stability of the system and end in a black out. This means that "the short-term" (hours) has an economic value. (iv) Electricity must be consumed when generated, the only means for storing electricity is to transform it into another form of energy, i.e. hydrogen, kinetic energy in pumping plants, etc. Physical commodities can be bought days or years in advance, stored, and consumed on demand. (v) Location matters and electricity cannot travel freely due to network constraints (Costa-Campi et al, 2020). In the current market design, grid capacity is utilised through the bidding zones in Europe or nodal prices in the US, while storable commodities can freely be transported.

Long term or forward markets are used to trade in advance (years or months) in over-the-counter markets, and consumers, generators and retailers can hedge their positions. In liberalised electricity sectors, short-term markets are essential given the characteristics of the commodity and play a dual role: they provide an efficient economic assignment of generation technologies to match with the hourly consumption and, even more important, they provide sufficient generation to cover an inelastic demand side.[7] In storable commodities, an occasional supply chain disruption can be compensated with stored or substitutes, but in electricity markets, a lack of supply results in blackouts and is also socio-economically costly. In sum, short-term electricity markets must always meet the demand, i.e.

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[6] Flowing hydraulic plants are hardly dispatchable, while the pumping plants are dispatchable.

[7] In Europe, the imbalance settlement periods are moving from one hour to 15 minutes to better match the variability of the supply side (Regulation (EU) 2017/2195).

ensure the short-term security of supply, a challenge increasing with higher shares of variable renewables in the generation mix.[8]

2.2. Electricity markets and initial conditions

The growing involvement of the public sector in the energy landscape has been a unanimous global response to the gas market crisis, prioritizing the affordability problem as quick as possible. This is not unexpected, given that the current 'competitive electricity systems arose in the context of thermal generation with dispatchable production and increasing variable costs' (Hogan, 2022). In Europe and elsewhere, availability of plentiful natural gas and affordable prices supported the liberalisation process.

Electricity markets have several characteristics that differ from a perfect competition market: (i) The number of suppliers is limited and not all the suppliers can bid their product when they want (renewables depend on sun or wind), (ii) Electricity as product is homogeneous, but not its primary source, generated with diverse technologies and costs (sun, wind, oil, gas), in other words, suppliers are not price takers; (iii) There might be asymmetric information between consumers, suppliers and regulators as some energy is traded in long-term over the counter markets. As consequence, some market instruments that might be effective in other commodity markets may not be straightforward applicable to electricity markets.

Most electricity systems and markets have evolved significantly since then. Does this necessitate that the government should take control of the markets in deciding 'what to produce'; 'how to produce'; 'for whom to produce' and 'at what price'? The second theorem of welfare economics states that, a given desired allocation of endowments, competitive profit-maximizing enterprises can do as well as the best central planners to attain an efficient allocation of resources (Stiglitz, 1991). The role of government, therefore, becomes important in terms of the initial allocation of resources following which the competitive market will produce a Pareto efficient outcome. In other words, there does not exist a single or unique efficient market outcome. Rather, for any given initial distribution of endowments, markets deliver a corresponding efficient outcome. In electricity markets, this includes the terms and rules for participating technologies, despatch, and remuneration of them.

The lesson implied for the electricity market is that the technological structure (fuel mix) shapes the marginal supply curve in the short-term market, while the national social and economic activity[9] shapes the demand curve. Its composition sets the market outcomes (price and quantity), social welfare and its distribution between consumers and producers. The differences in the cost of generation technologies in the mix and the quantities of their capacity under the marginal cost curve

[8] When variable RES production increases, other technologies should adjust and reduce their outputs.
[9] For instance, economic activity related to the primary, secondary and tertiary economic activity.

determine the shape of the supply curve, the market price, as well the distribution of welfare between produces and consumers and the effects of external shocks.

2.3. The energy policy trilemma

In the energy systems it is necessary to balance the three pillars, or objectives, of the energy trilemma: sustainability, security of supply, affordability. Sustainability relates to the green transition and avoidance climate change and its impacts, supply security aims to minimize the potential disruption of supplies, while affordability is concerned with the economic costs and distributional aspects of energy. Two of the 'first principles' of economics posit that competitive markets (i) produce efficient outcomes, and (ii) that they maximise social welfare. However, in electricity markets both are challenged.

There has been a gradual and subtle shift in the role of the markets as policy instrument. The competitive and integrated European energy markets are no longer meant to mainly improve economic efficiency and competitiveness. Instead, they are increasingly being employed for cost-effective delivery of the socio-economic-environmental objectives of the trilemma.[10] A recognition of this shift can give a clearer perspective for the proper role of energy markets and their design. Failure to do so can blur the purpose of market interventions and policies. For instance, the demand and subsequent price increases that followed the relaxation of Corona restrictions tested, the tolerance level of the cumulative effect of successive price increases from various charges and policy measures of the preceding years. During the recent energy crisis, an inflection point seemed to have been reached beyond which governments have deployed various price and income support measures to protect the consumers and industry.

However, at closer inspection, the pillars of the trilemma exhibit some characteristics of public goods. Economic theory suggests that, as in other cases of market failure, markets fail to deliver or under-deliver public goods. This in turn makes a case for potential public sector involvement to correct the market failure. Governments can and do use economic and market instruments to achieve a desirable balance of these objective. As such, the provision and balancing the trade-offs of the elements of the energy trilemma becomes a matter of public policy that cannot be transferred to the left to the market without some forms of oversight and intervention.

Applying the equi-marginal principle of welfare economics and cost-effectiveness to this case suggests that, conceptually, it is desirable to equalise the marginal cost of provision of the three components of the trilemma. As mentioned earlier, markets cannot be expected to deliver public goods, let alone a desirable combination of them. Therefore, governments need to recognise and conceptualise, these, however vague, objectives in terms of their marginal costs. Albeit this will be a somewhat subjective exercise it offers a structured view to frame the problem at hand. In the following we discuss several instruments aimed at the objectives of the trilemma, while considering there may exist potential

[10] Recall that cost-effectiveness is a necessary condition, but not sufficient, for an efficient outcome.

trade-offs between them. The relevant sections for the core subject of the paper and each of the trilemma objective are indicated in Figure 1.

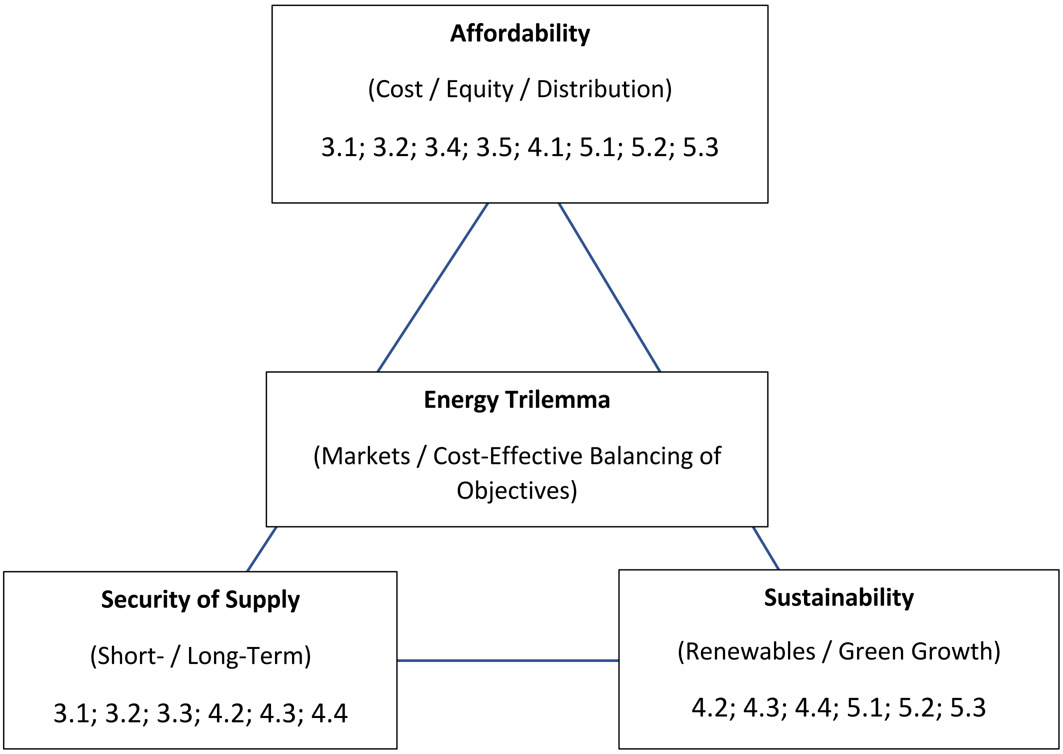

Figure 1. The energy trilemma objectives. Numbers in each box indicate sections in which relevant instruments are discussed.

3. Market allocation mechanisms

3.1. Long-term markets

In highly decarbonized power systems, long term contracts can be beneficial for generators and consumers. For generators, long-term contracts ensure a fair revenue to recover their sunk investments and isolate from cannibalization, especially in peak hours with peak renewable production. For consumers, long-term contracts provide stable prices, thus avoiding price volatility in exchange for paying some premium. In the wake of the recent crisis, the insolvency of many retailers and affordability problem is partly due to low hedging positions in long-term markets. Indeed, the liquidity of forward markets decreased in most European countries in 2021.[11]

However, a question is why many consumers (retailers) and generators have historically opted for the short-term markets instead. A prisoner dilemma might explain this: large consumers seek to benefit from temporal low hourly energy prices instead of paying a premium, and some generators seek to benefit from the temporal high hourly prices. Another explanation can be the administrative barriers related with these long-term contracts.

There are several instruments in the long-term markets. First, in the past decade, Power Purchase Agreements (PPA) have increasingly been used by renewable plants to hedge their high capital investments.[12] This instrument is also an alternative to the public funding for renewables. However, countries should remove unjustified administrative barriers, provide credit guarantees or directly pool demand to remove barriers for small customers and boost PPA (European Commission, 2022b).

Second, Contracts for Differences (CfD) are used to provide public support for renewables. They ensure minimum revenues for generators: when short-term prices are below the minimum revenue, subsidies fund the deficit. Conversely, when short-term prices are above the threshold, generators should return the surplus. This instrument also hedges consumers against short-term market volatility. In the UK, they worked well during the crisis as a cushion against extreme market prices. At some level, CfDs have some resemblance to profit sharing arrangements and can also be made technology specific. It is noteworthy that if the terms of CfDs are with reference to some market price trigger, in many markets this price is set by gas power. Therefore, there is an interdependence between the gas power and renewable CfDs is present. Gas or electricity price caps can be set with this link in mind.

Finally, another solution to displace energy from the short to the long-term might be to limit the traded energy in the short-term markets (or a minimum volume in the long-term markets). This would increase the hedge position of agents and decrease the price volatility for consumers. In China, the recently published '2023 Mid-Long Term Power Trading' policy requires that market participants purchase at least 90% of their previous year's energy needs, in long term contracts.[13] However, defining such a threshold could also require including minimum quotas of renewables in the long-term markets in order to avoid that generators prioritize trading polluting dispatchable technologies at the

[11] Liquidity can be measured by the churn factor, which is the overall volume traded as a multiple of physical consumption (Wholesale Electricity Market Monitoring, 2021).
https://www.acer.europa.eu/sites/default/files/documents/Publications/Progress_report_European_wholesale_electricity_21.pdf
[12]Bloomberg.https://about.bnef.com/blog/corporate-clean-energy-buying-grew-18-in-2020-despite-mountain-of-adversity/
[13] NDRC (2022).

expense of variable renewable technologies.[14] This measure can help increase the liquidity and reliance of actors on the long-term market.

3.2. Transparent long-term markets

Many hold the view that investors and long-term or forward over the counter markets receive signals from the short-term markets that translate into long-term investments and contracts that arrive in time and in sufficient quantities (DEA, 2018). Under a scenario of rising electricity prices, owners of long-term purchase contracts at low prices could obtain high premiums by reselling them to retailers. However, it has been difficult to locate and quantify the potential windfalls profits, which indicates that these markets are not sufficiently transparent, electricity can be traded in private markets between two parties without a central exchange and the transactions can add up to staggering amounts. A question is whether the crucial link between short-term and long-term markets can entirely be left to markets alone. Standardisation of long-term contracts and transparency of them can increase the clarity of the market. Regulators can implement big data technologies to identify potential gaming and windfall profits from abusive practices.

3.3. Splitting the markets: The "Greek Proposal"

The idea of the separation of short- and long-term markets, or those of gas and electricity markets, or those of conventional sources from renewables enjoys some support. For instance, the "Greek Model" proposes dividing the short-term markets between resources that operate when available and not on-demand (nuclear, high-efficiency cogeneration, sun, wind and mandatory hydro), and the rest of on-demand resources (fossil plants, hydropower operating at peak times, demand response and storage). The Greek Government estimates that splitting the market would reduce 50% the electricity prices, solving the affordability problem. The first group would be funded by CfD reflecting total levelized costs, while the second with the marginal costs.[15]

These forms of interventions seem to be difficult to implement in practice and the threat of legal action and litigation can deter decision makers from major interventions. Moreover, splitting the markets could harm market ability to dispatch the appropriate technologies, do not provide the correct efficient price signals to consumers, and could curtail renewables in equal terms than cogeneration (pro-rata criteria is proposed).

[14] For instance, long-term contracts for non-renewable dispatchable technologies (combined cycles) might block the participation of renewables during peak production, i.e., the most windy or sunny hours (Batlle et al., 2022).
[15] For further details see: https://data.consilium.europa.eu/doc/document/ST-11398-2022-INIT/en/pdf

3.4. Pay-as-clearing vs. pay-as-bid

A market-based (re)arrangement of the initial allocation of endowments and welfare is in the form of lower price by moving from ‘pay-as-clearing‘ wholesale market towards a ‘pay-as-bid‘ or ‘cost-based’ wholesale market. A ‘cost-based’ wholesale market provides higher consumer surplus than a unique marginal price for all the technologies, namely ‘price as clearing‘. For instance, the price component for thermal generation is set at the marginal cost of each plant consisting of fuel input and the technical characteristics of the plant. Also, important is to include the price of carbon and other emissions with variable costs such as fuel since economic dispatch seeks the lowest total aggregate system variable costs. There might be an asymmetric information problem as generators might have incentives to declare higher operational costs and beyond the most efficient solution. Finally, although pay-as-bid could improve the affordability, technologies with very low operating costs as RES, won’t have possibilities to recover their capital investments if they bid only at their marginal operating cost of almost zero, affecting the long-term sustainability and security of supply. Moreover, pay as bid can reduce incentives to implement innovative solutions.[16]

Marginal vs. average costs in short-term markets

A possibility in the market design to avoid negative prices is including second-best solutions such as linking the price (p) paid for by consumers to the average cost of generation (i.e., p = fixed costs (fc) + variable costs (vc)) instead of the cost of marginal generation technology (e.g., gas-fired plants as is often the case) (Battle et al., 2022). This might alter the merit-order dispatch profile mechanism as shown in Figure 1 when the dispatch mechanism is based on ‘average-cost pricing’ rather than ‘marginal cost’ pricing.

[16] For further details, see page 11 in “Preliminary Assessment of Europe's high energy prices and the current wholesale electricity market design” published by ACER (2021).

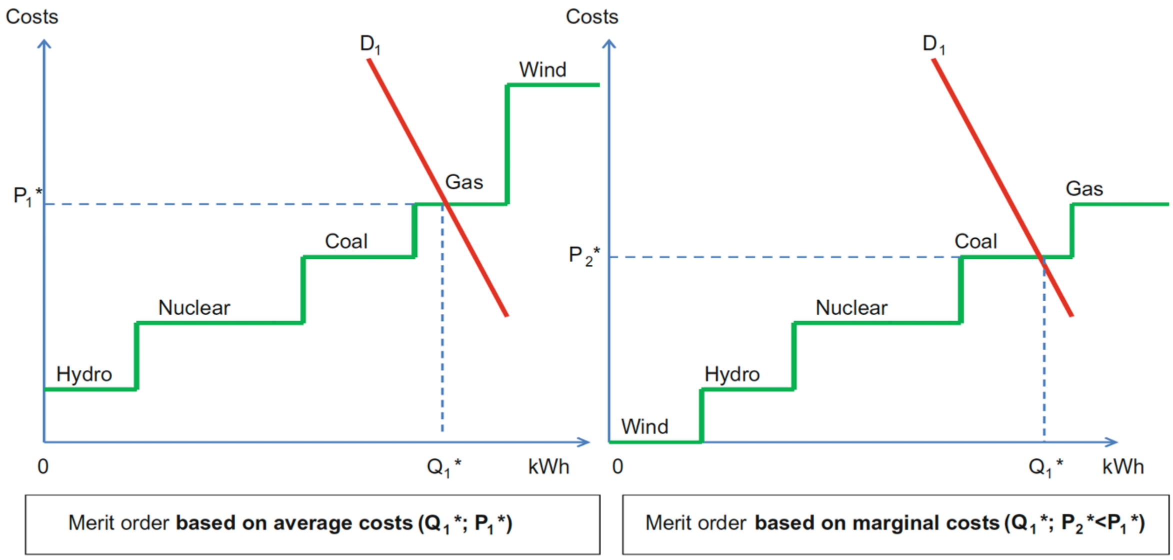

Figure 1: 'Short-term Marginal' cost versus short-term 'average' cost-based dispatch

Source: Benhmad and Percebois (2018)

The second-best solution based on average cost-based market clearing maybe more effective in a carbon-constrained world with no coal and gas than in the present state of transition with a high share of renewables. This approach offers higher supply stability, but at a higher market-clearing price than the first-best approach which invites higher supply intermittency. The incentives for low-cost generators to extract rents given a uniform price auction clearing mechanism is strong under the merit-order based dispatch mechanism irrespective of the first-best (P=MC) or the second-best (P=AC) market clearing mechanism.

The current market design based on marginal-cost pricing can lead to the 'missing money' problem which is the inability to cover the full cost of production for an existing generator. An ever-decreasing market clearing price might not be an efficient economic incentive to entry for new renewable generators in the short-term markets since the opportunities to extract rents are diminished. Figure 2 shows that an increase in supply brought about by renewables depresses the overall short-term price towards zero and therefore lowers the rent.[17] Such misaligned price signal is a threat to long-term energy supply adequacy and can be avoided through complementary support mechanisms such as capacity payments to provide additional revenue streams, or through long-term instruments as explained later.

[17] This effect is also known as merit-order effect.

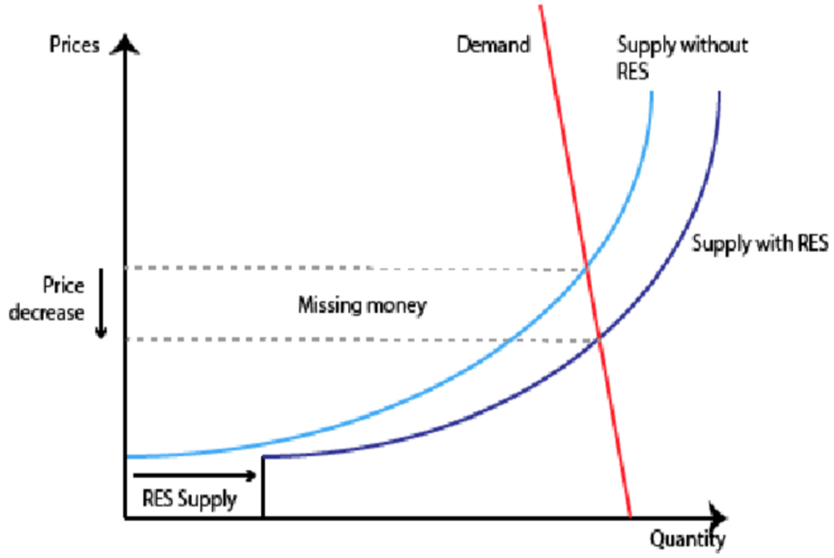

Figure 2: Missing money from the perspective of increased renewable penetration

In net pool wholesale markets, such as in the EU, the short-term market acts as a real-time balancing market to match the difference between the final real electricity demand and the previously traded energy in the long-term markets. Therefore, efficient price signals provided by the spot market matters as the EU electricity markets become more intermittent in nature due to greater renewables.

3.5. Price caps in the short and long-term markets

When faced with sharp price increases, as in the 2021-2022 energy crisis, an instinctive policy reaction is to consider price caps as a remedy, either in the short-term electricity markets or in the gas and coal markets. Many scholars and practitioners, supported by economic theory, assert that price caps might have negative long-term implications by reducing investment incentives which, in turn, could instigate future supply shortages.

Political economy of energy prices presents a more nuanced picture. For a vital commodity or service such as energy there always exists an observable or unobservable price cap. As such there can be no credible guarantee that one will never exist. It is unrealistic to assume that prices can rise for a significant length of time without any intervention. For that reason, there is always a political economy motivated price cap, whether stated or otherwise, that reflects the tolerance level of the economy and society.[18] The argument that price caps are harmful or guarantees had been given may serve as bargaining arguments, but ultimately the political economy reality will dominate the theoretical economic efficiency argument i.e., a fairer distribution of welfare takes priority over its overall size. In

[18] The current informal price caps might be related to the different values of the loss of load across the countries (VoLL) which quantify the utility provided by electricity to customers. Therefore, it is easy to consider that higher VoLL might have higher potential price caps (Newbery, 2016). VoLL show the estimated amount that customers would be willing to pay to avoid a disruption in their electricity service.

public policy there are instances where some economic efficiency is given up in return for a fairer distributional outcome. As mentioned earlier, energy markets have not been text-book examples of perfectly competitive markets.

Policymakers cannot be expected to keep a no-price-cap promise in all circumstances and such assurance cannot be regarded as a guarantee. Likewise, the industry cannot assume that there will never be a price cap. What is certain is that, regardless of theoretical arguments and political assurances, there will always exist an energy price cap, explicit or implicit.[19] Acknowledging this matter will bring the debate on price caps out of the sphere of theory and bargaining rhetoric and firmly into the more relevant domain of political economy and stakeholders can begin to discuss the level of price caps rather than its existence.

In short-term markets, price caps might threaten the security of supply if some technologies cannot cover their extremely high fossil fuel costs and might limit incentives to market participants during peak hours: consumers do not reduce consumption, generators do not increase production, and storage does not make an efficient use of their facilities. Consequently, price caps in short-term markets might constraint the ability to meet all the demand in peak times, namely the role to ensure the security of supply.

Setting a price cap in the over-the-counter markets seems almost impractical. Would this be beneficial by consumers? This is not clear and depends on two main issues. First, if the agreed long-term prices include excessive coverage premiums against future high fuel prices, consumers could pay higher prices, affecting the affordability targets. As explained earlier, this does not mean that long-term contracts cannot be supervised. Second, trading most of the pollutant technologies in the long-term markets could block the participation of renewables in the short-term markets, thus constraining the sustainability target. Therefore, it is important to assess undesirable effects of a price cap on long-term and short-term markets to ensure affordability and sustainability targets of the trilemma.

4. Non-market instruments

4.1. Sector coupling – Electricity and gas

The notion of decoupling, in the broad sense of the word, has been one of the constants since the start of the liberalization of the energy sector. It is once again back on the electricity sector agenda, only this time, in terms of costs and prices. Liberalization of electricity markets decoupled the regulated price of electricity from the cost of it. Instead, the spot market price was set by the cost of

[19] Nowadays, there is a legal price cap in wholesale markets: https://www.reuters.com/business/energy/nord-pool-sets-new-baltic-power-price-thresholds-prevent-spikes-2022-11-16/

marginal generation plant. Competitive energy markets have also coupled gas and electricity prices through power generation from natural gas, often setting the wholesale marginal price. Moreover, electricity sector reforms have sought to decouple the regulated charges and revenues of natural monopoly networks from their costs through incentive regulation regimes.

The recent calls for market intervention to essentially decouple prices from marginal costs aim to link them instead, in some way, to the underlying generation costs of technologies contradict some theoretical justification for efficiency enhancing. This argument may, however, be justified on grounds of redistribution and equity of, albeit a smaller, total social welfare. Therefore, although energy system integration remains a policy priority, there appears to have been an implicit rebalancing of the trilemma, due to the security of supply crisis of 2022, from environmental objectives towards equity and affordability.

At the same time, more recently, policy makers have sought to couple gas and electricity (and other energy) sectors through promotion of Energy System Integration (ESI) to take advantage of the synergies for economic efficiency and environmental concerns between the two sectors (Jamasb and Llorca, 2019; Cambini et al., 2021). Once the technical difficulties are overcome, to function efficiently, ESI is also dependent on efficient price signals across the integrated sectors. It is not clear how an efficient coupling of gas and electricity sectors can be achieved when gas and electricity prices are effectively decoupled, and other additional regulations may be placed.

4.2. A role for flexible consumption

It is challenging to operate the power system when consumers have a rigid and low price-elasticity profile, and the generators are conditional to "random" and volatile weather conditions, i.e. sun, wind or precipitation. Consequently, matching a rigid consumption with variable renewables has meant the recurrent dispatch of gas-fueled plants when the hourly renewable production is not sufficient, or curtailment of renewables when the hourly consumption is not sufficient. This explains the high level of volatility in the short-term marginal prices.[20]

Some consumption cannot be delayed (e.g., for lighting, cooking, heating, or cooling), while others can be delayed for hours (electric vehicle charging points, electric water heating devices or storage devices) and operated under demand response schemes operated by providers of energy services.[21] Therefore, the question is why consumption remains rigid and does not match with the hourly

[20] Under the gas price shock, this effect was seen in Spain and Portugal. Some weekends in September 2022, minimum prices were about 20€/MWh or near zero at noon, while the maximum prices were above 150€/MWh or higher in the same day. For instance, on 3rd. and 4th. September 2022. https://www.omie.es/en/market-results/daily/daily-market/daily-hourly-price?scope=daily&date=2022-09-03

[21] Directive 2012/27 on energy efficiency states that "Demand response can be based on final customers' responses to price signals or on building automation" and "provides a mechanism to reduce or shift consumption, resulting in energy savings (…) and through optimal use of networks and generation assets".

renewable production? Consumers could not face enough efficient incentives to implement demand response programs. For instance, when retailers provide flat tariffs to consumers, consumers do not have hourly incentives to move their consumption.

The wide implementation of advanced metering infrastructure (AMI or smart meters), as in some countries, is a starting point. However, in most countries, the full potential of AMI is yet to be utilised. Some countries have implemented time-of-use tariffs (ToU) to incentivize consumption in some hours over others (IRENA, 2019). These tariffs can be static (determined in advance) or dynamic (determined in real time), providing different economic incentives to consumers.

In sum, there is a need to move from a model where supply closely follows the consumption, to a model where consumption follows the renewable availability at each hour. Therefore, it is essential to design efficient real-time economic incentives to enable consumers to change their inelastic demand, i.e. hourly tariffs to incentivize charging the Electric Vehicles considering the renewable production. If these incentives were not sufficient, additional interruptible schemes or demand response could be implemented at peak consumption hours that coincide with the low renewable supply availability. These mechanisms would help the short-term markets to ensure the short-term security of supply.

Finally, it is important to highlight the role played by energy storage. Storage remains in an incipient stage and consumers do not have sufficiently strong hourly economic incentives to implement flexibility solutions in buildings. Large pump storage plants, hydrogen, and small storage could consume the surplus renewable production, which contributes to smooth the wholesale prices during the day. Here, marginal prices could provide more efficient economic incentives than under average-cost pricing, as the difference between the peak and off-peak times might be higher. Therefore, changing the current market design might affect the incentives to build large scale storage, which should be examined further.

4.3. Location matters: networks as market enablers

Under the European market design, bidding zones correspond to the largest geographical areas within which generators and consumers can exchange energy in the same short-term market (cite). They are defined based on the structural grid bottlenecks and in most of cases, each country belongs to a unique bidding zone.[22] Therefore, each bidding zone has its own bidding price in the short-term markets.

[22] For those countries with relevant grid bottlenecks in their area, there are several bidding zones. This is the case of Italy, Norway, and Sweden.

Despite structural grid constraints in the bidding zone definitions, grid operators must always validate ex-ante if the hourly outcomes from the short-term market are technically feasible, i.e. if the grid infrastructure can allocate the energy flows from the scheduled generation and consumption. Otherwise, grid operators should redispatch units, i.e. preventively curtail specific scheduled units (consumers or generators) or start other ones non cleared in the short-term markets (Regulation (EU) 2019/943). In 2019, these remedial actions in Europe amounted to 61,8 TWh with a cost of 2.25 million Euros, with the corresponding impacts on the affordability (ACER, 2020). In many cases, these actions involve curtailing scheduled renewables, also affecting the sustainability principle of the trilemma (Davi-Arderius and Schittekatte, 2023). The high volumes of remedial actions highlight insufficient grid capacity to connect new renewables in some nodes.

To address this problem, grid operators should reinforce and build new networks. However, these are costly and social rejection to new grid has increased. As an alternative, flexibility services can be an efficient and faster choice.[23] Participants in these services -known as flexibility providers - receive economic compensation in exchange for modifying their consumption or generation profiles during some time, on request of the grid operators. However, the implementation of such flexibility services requires creating new markets, coordinated with the current short-term and balancing markets.[24] Thus, flexibility services enable integrating more renewables, and pressing prices downwards. Prices from flexibility services provide locational price signals indicating deficit (or surplus) of flexible resources in each location.

As an intermediate solution, time-of-use (ToU) network tariffs can provide time incentives to consumers or generators to minimize grid congestion and, ultimately, remedial actions. This is already feasible with the current smart metering technology. In 2018, ToU tariffs were implemented in 33% countries in Europe (Trinomics, 2020).

4.4. Independent long-term energy planning

A public authority can oversee the long-term planning and development of the sector, ensuring higher transparency in the long-term market. In the UK, an anticipated new body Future System Operator (FSO) may play a strong role in long-term planning of the electricity system, also ensuring a strategic coordination between energy sectors, following the whole system approach.

[23] In the connection of a new consumer or generator, grid operators should evaluate its available grid capacity under normal and non-normal conditions. When there is not enough grid capacity, some grid reinforcements are necessary. Precisely, flexibility services can be very an efficient alternative to all these necessary grid reinforcements and connect them without waiting for building new grids.

[24] The scheduled energy from the short-term markets should consider the changes in the consumption or generation profiles by flexibility services.

An independent authority such as FSO can assume operational independence from the system operator and the government to provide independent advice and strategic direction to the regulator and the government. Its main role is driving progress towards a net zero objective while ensuring the other two pillars of the energy trilemma: i.e., energy security affordability for consumers are also upheld.[25]

5. Redistributive mechanisms

5.1. Negative prices and missing money

Efficient market design with increasing reliance on intermittent renewables such as solar and wind with very low marginal costs is a challenge when today's electricity markets were designed for increasing marginal cost of supply (Hogan, 2022). As a result, negative prices are increasingly observed in the short-term markets when the supply offered at negative prices is greater than the demand. [26] This is known as cannibalization.

These events primarily occur at times of high renewables supply influx such as in the mid-day when intermittent renewables (e.g., rooftop solar, large-scale solar, wind) compete to dispatch their energy with non-renewable generator that face relevant costs to start/stop (e.g., a coal-fired or nuclear generator). However, are negative prices necessarily bad? From economic and technical perspective, they are not. Negative prices in short-term markets signal a temporal deficit of consumption that could lead to curtailment of renewable production. Moreover, negative prices might be an additional incentive to trade this energy in the long-term markets to hedge generators. In sum, negative prices could be an efficient incentive to consume when needed, also to promote installing storage instead of directly curtailing a surplus of renewable production. Moreover, they provide incentives to hedge renewables in the long-term markets.

Is a wholesale electricity market with 100% renewable energy viable under the existing market-design and ensures the long-term security of supply? Substituting polluting plants with intermittent renewables requires deploying firming technologies such as pumped hydro or combined cycle given the unpredictability of solar and wind resources to address short-term mismatches between demand and supply (Gilmore et al., 2022). In this case, complementary capacity markets might be an efficient solution to have firm plants to address deficits of renewable production and ensure security of supply. These markets can address extremely low energy prices, but over procurement of capacity could depress the future prices, amplifying the initial problem (Newbery, 2016). Therefore, the case for

[25] https://www.ofgem.gov.uk/energy-policy-and-regulation/policy-and-regulatory-programmes/future-system-operation-fso

[26] In Europe, the number of negative price occurrences was 925 (2019), 1,926 (2020) and 952 (2021). Source: Acer dashboard about the evolution of the European wholesale market trends 2016-2021. https://www.acer.europa.eu/news-and-events/news/wholesale-electricity-markets-monitoring-2021-rebound-demand-more-coal-higher-electricity-prices-and-more-electricity-renewables-fossil-fuels-0

deployment of firming technologies such as pumped hydro and storage including green hydrogen is appealing.

5.2. Taxation of windfall profits

When considering taxation of profits in the electricity markets, it is important to distinguish between the different sources of profits i.e., resource rents, normal market profits, and windfall profits. Nowadays, all the corporate profits are taxed in each country. These profits have different origins and are often addressed by different policies.

In the current context of rising gas prices, some technologies have earned significant windfalls leading to calls for taxing or expropriating them (International Energy Agency, 2022). Windfall profits are, by definition, supranormal and unexpected gains. The argument that taxing windfalls will result in lower future investments is not based on theoretical arguments and empirical evidence. Investors do not invest in anticipation of windfall profits, rather they require stable regulatory and policy framework for normal profits. Economic instruments such as CfDs can help achieve this. The case for taxing the windfalls of non-renewables is that unanticipated gains are not part of the normal investment planning and decisions.

In the case of renewables, subsidies and support mechanisms for innovation and capacity deployment have fostered their participation in the generation mix to address a market failure in the incipient stage of deployment. Many renewables are increasingly competitive, and public subsidies are decreasing.[27] In the case of renewables benefiting from subsidies and other supports mechanisms, it can be argued that the windfalls and resource rents should accrue to taxpayers and consumers respectively. Note that the debate surrounding windfall gains and taxation is mainly a distributional matter. Jamasb and Sen (2022) discuss aspects of the emerging potential for renewable resource rent, state involvement in the sector, and a comparative governance regime with reference to offshore wind sector.

A tax on resource rent would normally not be applicable to existing or old renewables operating under historical contracts. A higher tax rate on normal profits might be distortionary and increase the deadweight loss due to misaligned incentives if the possibilities to substitute renewables with non-renewable output are large or the economic viability of renewables decreases. Moreover, this could adversely affect the allocation of capital in renewables, delaying further investments thus, affecting the long-term sustainability and security of supply. What is important is the appropriate level of tax

[27] The case offshore wind is an example. There are signs that the diminishing role for subsidies already signify a growing potential for supranormal resource rents in the sector. LCOE for onshore wind and photovoltaics are between 30 to 70U$D/MWh in Europe. Source: International Energy Agency (2022). “Renewables 2021. Analysis and forecast to 2026” Available at: https://iea.blob.core.windows.net/assets/5ae32253-7409-4f9a-a91d-1493ffb9777a/Renewables2021-Analysisandforecastto2026.pdf

on normal profits. Finally, it is important to consider that new renewables are facing an indirect tax from long and complex administrative procedures that delay commissioning times, add uncertainties to investments and offset effects of subsidies. Reducing these inefficiencies should be a priority to ensure sustainability.[28]

5.3. Price caps post-market closure

A possibility to implement a temporal price cap in the short-term market applies to the Spanish and Portuguese wholesale market from March 2022 until May 23 and is known as the "Iberian exception". The price cap is set at €40/MWh during six months and increases until €70/MWh in the twelfth month. This measure is financed by the congestion revenue (France-Spain) and a charge imposed on the customers benefitting from the measure. [29] Although this measure consists of an artificial price cap in the short-term market, it could be considered as a redistributive measure because consumers in the regulated electricity tariff benefit from this artificial price cap, and the difference up to the closing short-term market is paid by consumers in the liberalized market.

As the Commission recognizes, price caps in some countries should be temporal and require a low cross border capacity because cross-border flows are calculated using the new price cap. As seen in other instruments, these price caps might neutralize the efficiency of price signals to consumers (generators) to reduce consumption (increase production), which is essential to exploit the available renewable production.

Other possibilities to decouple the peak marginal prices from the electricity prices is implementing an ex-post market clearing mechanism such as the Excessive Clearing Price Control Mechanism.[30] Under this mechanism, all generators don't receive the marginal price when the hourly marginal is above a predetermined threshold. Instead, the difference between its bid price and the marginal price is multiplied by a pay-out coefficient. Final price for consumers is lower.

[28] Lower uncertainties reduce risk investments and, ultimately, in lower capital cost associated to investments. https://energy.ec.europa.eu/topics/renewable-energy/enabling-framework-renewables_en

[29] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3550

[30] For instance, the cleared price is 300€/MWh (above the threshold of 180€/MWh), the pay-out equals to 80% and the bid equals to 100€/MWh. Thee generator would receive: 100+(300-100)*0.8=260€/MWh.

6. Conclusions and policy recommendations

Even prior to the recent crises, due to technological change and policy reorientations, energy market designs had been ripe for an overhaul. However, in the absence of an urgency, this was not high on the agenda. During the shocks, the long- and short-term markets have, supported by a range of demand and supply side regulatory and policy measures, to a large extent, ensured the security of physical energy supplies. However, the implications in terms of extremely high prices, especially for the lower income consumers and energy intensive industries have been severe. Governments have urgently prioritized short-term measures to alleviate the affordability crises, while aiming to maintain the long-term sustainability and security of supply pillars of the trilemma.

The high price volatility highlights the need to increase the traded energy in the long-term markets, which can be made by mandatory quotas in the short and long-markets. However, instead of regulation-based instruments such as CfD or PPA can be used to reduce price volatility and excessive windfalls. Moreover, the consequences of preventing or forcing some technologies to participate in the market cannot be underestimated, and its implementation would not be immediate due to the existing contractual agreements. Adam Smith's vision of individual self-interest and the invisible hand as the guiding force in efficient market may also require a 'visible physical hand' in this market.

Table 1 summarizes the main instruments, also indicating their potential impact on each of the trilemma components: sustainability, security of supply and affordability. As we see in most cases, a positive impact on one component might be related with a negative effect in another one, due to the trade-offs among them.

Table 1. Summary of the main instruments

Proposal	Potential impacts on energy trilemma: Sustainability	Security of supply	Affordability	Description: Pros	Cons
CfD	+	=	+	• Minimizes volatility for consumers. • Ensures fair remuneration for generators	• Threshold might be not set at the optimal price level, impacting on the affordability
Minimum mandatory volume in LT markets	-	=	+	• Reduces volatility of final consumer prices • Consumers and generators are hedged	• LT on pollutant technologies might block the participation of higher shares of renewables in ST markets.
Maximum volume in ST markets	-	=	+	• Reduces volatility of final consumer prices • Consumers and generators are hedged	• LT on pollutant technologies might block the participation of higher shares of renewables in ST markets.
Higher transparency of LT markets	+	=	+	• Better regulatory oversight of LT contracts • Disincentivise gaming and abusive behaviours • Better quantification of windfall profits in LT markets	• Need to define standardization and rules for LT markets
Splitting the markets	?	-	?	• In theory, reduces the average price for customers.	• Harm market ability to dispatch the appropriate technologies. • Do not provide the correct efficient price signals to consumers
Pay as bid in ST	-	-	+	• Lower prices than marginal prices	• Some generators don't have economic incentives to produce under scarcity of generation. • Technologies with low operating costs cannot recover their investments.

					• Asymmetric information problem to oversight bid prices
Pay as clearing in ST	**+**	**+**	**-**	• All technologies have incentives to bid • Higher liquidity in ST markets	• All the technologies have the same incomes regardless their marginal costs.
Price cap in LT and ST markets	**-**	**-**	**+**	• Lower price for customers.	• Consumers (generators) do not receive peak price signals to reduce consumption (increase production). • Might displace volume to LT markets (if they are OTC).
Price cap on renewables	**-**	**-**	**+**	• Lower price for customers.	• Consumers (generators) do not receive peak price signals to reduce consumption (increase production). • Might displace volume to LT markets (if they are OTC).
Coupling electricity and gas	**?**	**?**	**?**	• Not clear the potential benefits	• High uncertainty when prices of electricity and gas are decoupled.
Time-price signals to consumption	**+**	**+**	**?**	• Consumers have efficient economic incentives to change behavior considering the availability of renewable production. • Incentivize implementation of demand response programs.	• Passive consumers face higher prices. • Only valid for specific type of consumption (water heating devices, Electric Vehicles). Other consumption cannot be delayed. • Risk of social rejection.
Interruptible demand response mechanisms	**+**	**+**	**+**	• Avoids extreme peak short-term prices. • Limits potential market power in the short-term markets.	• Gaming risk between other ancillary services.
Grid flexibility services	**+**	**+**	**+**	• Consumers have efficient economic incentives to change behavior and implement demand response. • Grid can allocate more renewable capacity.	• Gaming risk between other ancillary services.
Independent long-term energy planning authority	**+**	**+**	**+**	• Better long-term energy system planning.	• Ensuring the transparency and independency of this authority from politic interests might be challenging.
Capacity markets	**=**	**+**	**?**	• Very useful when prices in ST are very low • Ensure economic feasibility of firm back up technologies.	• Difficult to set the optimal level to capacity to procure. • Risk of capacity over procurement

Tax on resource rent	-	-	+	• Easy tax revenues in the short term.	• Directly jeopardize the economic viability of the existing renewables, directly compromising the short-term security of supply.
Tax on fair profits	-	-	?	• Easy tax revenues in the short term.	• Adversely affect the capital allocation of resources in renewables, delaying future investments thus, affecting long-term sustainability targets and security of supply. • Generators might bid higher prices to cover tax costs.
Tax on windfall profits	=	=	+	• Easy tax revenues in the short term.	• If they are permanent or excessive, delaying future investments thus, affecting the long-term sustainability targets and security of supply.
Iberian exception	+	-	+	• Lower ST market price.	• Cross border flows might increase. • Consumers (generators) do not receive fully efficient peak price signals to reduce consumption (increase production).
Excessive Clearing Price Control Mechanism	=	?	+	• Final price for consumer is lower. • Windfall profits decrease.	• Generators can bid at higher prices than its marginal cost. • Setting the optimal threshold to implement the mechanism requires deep analysis.

Note: * the potential impacts on each pillar of the energy trilemma can be positive (+), neutral (=), negative (-), unknown (?); ST means short-term markets; LT long term-markets.

The inframarginal rents, windfalls, and renewable resource rents need to be made easier to locate and measure. This requires transparency, monitoring, and standardisation of contracts and transactions. Taxing the normal profits of renewables contradicts the market failure argument as the basis to support renewables through technology push and market pull incentives. Such tax is distortionary and increases the deadweight loss due to misaligned incentives if the possibilities to substitute renewable output with non-renewables, because of the tax, are large. On the other hand, both windfalls and renewable rents, often made feasible by technologies supported by rate- or taxpayer subsidies, can be taxed. Attention should be paid to the removal of administrative burden to the connection of new renewables, which represent a non-minor current high tax for them. Splitting the markets between conventional capacity and renewables could reduce market efficiency or provide inefficient price signals to consumers and producers.

Most attention has been on market design improvements, but there are also non-market instruments with potentials on the energy trilemma. First, coupling electricity and gas to take advantage of synergies between sectors. Second, consumption should have economic incentives to be flexible, elastic and better follow the available renewable production, not the opposite. Specific demand response and flexibility services could be implemented to deal with peak consumption coinciding with low available supply. Third, locational components are relevant because of the networks, which are essential to fully implement the scheduled generation and consumption from market clearing. Implementation of flexibility services could efficiently address grid constraints and allocate higher shares of renewables. Finally, an independent strategic authority can assume the responsibility for long-term planning and ensuring sufficient investment. Security of supply can be a mandate of this authority and long-term markets. However, there is a lack of international experiences.

As discussed, all instruments have certain strength and inefficiencies. Each mostly benefits a trilemma component, but there might be trade-off with the other two. Improvements on the market design and other complementary instruments need deep analysis, independent studies and rash decisions could not be the best. In this debate, the possibility to test some of these proposals at low scale using specific regulatory sandbox is not feasible, which highlights that the electricity markets are quite far from other more innovative markets such as the financial.

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