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POTENTIAL LIMITATIONS OF MARGINAL PRICING FOR A POWER SYSTEM BASED ON RENEWABLES

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CONTENTS

FIGURES

BOXES

ABBREVIATIONS

CAPEX	capital expenditure (investments needed to build the plant)
CfD	contracts for differences
CRM	capacity remuneration mechanism
CSP	concentrated solar power
DiRE	dispatchable renewable electricity generation (CSP, biomass, hydro with reservoir...)
EF	flexibility resources, including DiRE, demand response, demand-side management, storage, power plants operated with green hydrogen, and other energy system integration elements
FiP	feed in premium
FiT	feed in tariff
FF	fossil fuels
FF-base	base load fossil fuel electricity generation
FF-peak	peaking fossil fuel electricity generation providing flexibility
GC	green certificates
LCOE	levelised cost of electricity (covering life-cycle costs of generation, including OPEX and CAPEX)
MC	marginal costs
MP	marginal price: In a marginal market it is set by the most expensive bid needed to cover the demand (clearing bid)
OC	opportunity costs
O&M	operation and maintenance costs
OPEX	operating expenditure
PPA	power purchase agreement
PV	photovoltaics
VRE	variable renewable electricity generation (PV, wind,...)
WACC	weighted average cost of capital

The following graphical elements are used in the simplified figures presented in this Technical Paper (VRE = variable renewable energy; DiRE = dispatchable renewable energy; EF-other = other energy flexibility; FF-base = base fossil fuel power generation; FF-peak = peak fossil fuel power generation):

VRE generation
DiRE generation
EF - other
FF-base generation
FF-peak generation
Carbon price

BASIC CONCEPTS

This section introduces some basic concepts about marginal pricing markets to make the discussion in this Technical Paper accessible to a wider readership.

In a marginal pricing market,[1] participants bid at the marginal cost[2] (MC). The (short term) marginal cost[3] is constituted by the operation and maintenance costs[4] (O&M-OPEX) plus the opportunity cost (OC), which represents revenues foregone by not selling the electricity at another point in time or market. Opportunity costs may also include the requirement to recover life-cycle costs through limited participation in the power system, such as those that may drive price bids during scarcity events.[5] In most cases, the marginal cost consists primarily of O&M costs and hence is below the LCOE, which also includes capital expenditures (CAPEX): MC < LCOE. For plants operating on variable renewable energy (which are CAPEX dominated), the difference between the marginal cost and the LCOE is higher than for fossil fuel plants.

In a marginal pricing market, all participants are rewarded at the clearing price, which is the marginal cost of the most expensive bid needed to meet demand fully. Therefore, the clearing generator is rewarded at its $MC_{clearing}$= MP, but all the other generators contributing to supply the demand at this point in time are retributed with a price above their marginal cost (MP > MC_{other}). The differential between the MP and the MC is what should allow generators to recover its CAPEX and earn a profit.[6] Generators' profits, in turn, are the signal that should enable investments to guarantee power system adequacy.[7]

VRE presents three distinct characteristics regarding its participation in a marginal pricing market: 1) its OPEX and OC – and thus its marginal cost – are very low; 2) its cost structure is heavily dominated by CAPEX; and 3) its generation cannot be increased beyond natural resources availability.

To operate succesfully, all participants[8] in a marginal pricing market must recover the LCOE (including profits[9]) over the plant's lifetime; otherwise there is no business model and no investments would be committed. Clarity on the prospect of cost recovery has a direct impact on perceived risks, which in turn are linked to financing costs: If the market does not provide a clear path to cost recovery,financing costs and LCOE increase.[10]

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1 *In a "marginal pricing market" the price is set by the bid from the last unit needed to cover the demand, with the price-setting bid being driven by the marginal cost of the last unit. But markets can be designed in different ways, with prices being driven by either marginal costs or average costs. In a short-term market (such as current wholesale electricity markets), generators decide whether to produce or not; hence, the market price is driven by the marginal cost. In a long-term market (i.e. competition takes place before investments are made), such as the long-term pillar of the dual procurement proposal (see Box-1), generators decide whether to invest or not; hence, the market price is driven by the average cost of production (LCOE).*

2 *Note that in imperfect markets (imperfect competition), when some participants have market power and use it, their bids may add a mark-up on top of O&M and main opportunity cost. This bid's mark-up may be understood as an extension of the opportunity costs component, and represents a distortion in market operation.*

3 *In this Technical Paper, when we refer to the marginal cost (MC) we always mean the short-term, short-run MC.*

4 *Which eventually would include the impact of carbon prices in FF-based generation.*

5 *A scarcity event occurs when demand exceeds available regular generation, requiring more expensive forms of generation to be called in. Since the more expensive generation clears the market, it sets the marginal price under these circumstances.*

6 *Note, however, that there is no guarantee that the differential between MP and MC across the lifetime of the plant will be able to fulfil the goals of CAPEX recovery and targeted profit generation. There is no "magic" in the market: the marginal cost of the marginal technology is unrelated to the average costs of the various generation technologies.*

7 *However, there is no guarantee this will occur. Whether these short-run price signals manage to encourage the investments needed for security of supply will depend on many factors, including its predictability. Relying on short-run price signals fundamentally unrelated to the life-cycle costs of the technologies needed for system adequacy may be a risky approach. The situation is still more critical when a fundamental overhaul of the power system, such as that involved in moving from fossil fuels to renewables, is at stake. Dual procurement (Box-1) proposes a more direct and efficient way to guarantee system adequacy.*

8 *Well, in fact all participants that survive the constraints imposed by this organizational structure. Those participants that do not manage to recover LCOE and generate profits must withdraw from the market because their permanence in it would be unsustainable. In this sense, the organizational structure constitutes a filter for what participants can remain in the game, and this filter does not necessarily align with the social value that potential participants could provide.*

9 *The LCOE includes profits as an adequate rate of return on invested capital through the WACC component.*

10 *Financing difficulties become barriers to entry as smaller players are unable to fund their investments with their balance sheet. This in turn underpins power dynamics that prevent maximizing the social benefits from the transition.*

ABOUT THIS TECHNICAL PAPER

This technical paper focuses on the aspects of marginal pricing that can become problematic during the transition and for a renewables-based power system. The paper is best understood as an extension of previous work (IRENA, 2020 and 2022a) on the challenges of adapting the organisational structures of the power system to the transition to an renewables-based power system. IRENA (2022a), in particular, delves into the systemic nature of the transition, with dynamics reaching far beyond market mechanisms to include social, political, administrative, environmental, and business-related aspects.

Although IRENA generally uses the term 'organisational structures' to include both liberalised and regulated systems and to convey the idea that even in liberalised systems the organisational structure goes beyond wholesale markets (e.g. additional regulated payments, public and corporate auctions), this technical paper focuses on liberalised markets.

In an electricity procurement structure based on marginal pricing, all generation is rewarded at the price offered by the most costly generator needed to meet demand. Marginal pricing of electricity has been successfully applied to the procurement of electricity for the last decades.[11]

In most of today's power systems, marginal pricing is used to procure electricity – including most of the resources required for flexibility – under a single structure. This has worked well where the technologies used were not vastly different in terms of their techno-economic characteristics. But when transitioning towards a renewables-based power system, the techno-economic characteristics of its two main components (bulk renewable generation and flexibility) diverge significantly from each other and from those of the dominant technologies in fossil fuel power systems. It is in this context that marginal pricing misalignments arise.[12] The misalignments discussed below arise for the most part when applying marginal pricing to the procurement of all, or almost all, electricity under one single structure – that is, when using the same mechanism to procure renewable generation and flexibility.

This does not mean that marginal pricing cannot or should not continue to play a significant role for renewable-based power systems, but its role needs to be adjusted to the characteristics of the involved technologies. In IRENA's proposal for a way forward in power system organisational structures (dual procurement) marginal pricing is considered as an important component for the flexibility pillar, but is not used for the other pillar (procurement of bulk RE generation). By separating the procurement of these two main services (renewable generation and flexibility), most of the current misalignments can be prevented. See Box-1 and (IRENA, 2020, 2022a) for further details.

This paper explores the fundamental reasons why marginal pricing is problematic as the main and only element of power system organizational structures, both during the transition and once the transition would be completed. There are two main reasons.

11 Economic theory has underpinned the choice of marginal pricing in most markets for uniform / undifferentiated products. An ideal marginal market maximises (economic) welfare for society, i.e. consumer surplus + producer surplus; incentivises producers to bid their actual variable costs (avoiding uncompetitive behaviors); generates the adequate investment signals for market participants; and creates incentives to innovate and improve technology to increase efficiency and reduce production costs. However, besides markets never being ideal, the capability of approaching these performances depends on the techno-economic characteristics of the technologies underpinning the power system, and during the energy transition these are bound to experience a radical change (from fossil fuel-era to renewable energy-era).

12 Note for instance that the MC of a price setting technology (such as a flexibility resource) is completely unrelated to the average costs of technologies providing the bulk of electricity in a renewable-based power system (VRE), with a cost structure (CAPEX-dominated) very different from most generation during the fossil fuel-era.

The first is related to merit order and cannibalisation effects, which reduce rewards to generators using variable renewable energy (VRE) as the transition advances, evolving towards marginal prices close to the O&M costs of VRE, which are a very small fraction of the life-cycle costs of these technologies.

Bids are ordered by its marginal price from lower to higher (merit order). Hence, as VRE penetration increases more expensive bids are left out of the dispatch or see a reduction of volume being dispatched and clearing prices reduce (merit order effect). Since the merit order effects take place when VRE generate, VRE technologies are the most affected by the reduction in clearing prices, hence disproportionately reducing its revenues from the market as the VRE share is increased (cannibalisation effect).

A corollary of this misalignment is the potential dynamic with existing VRE generators. In order to recover life-cycle costs under the current wholesale market structure, existing VRE generators need fossil fuel generators to remain in the system (so that they can clear higher marginal prices), and hence have an incentive to block the shift to higher VRE shares (barrier to new VRE entrants).

The currently high (due to fossil fuel price spikes) windfall gains of the infra-marginal producers[13] (especially renewable generators) and the future missing money for renewable energy generation (due to merit order and cannibalisation effects) are two sides of the same coin. Under the current organisational structure the marginal cost of the marginal technology is unrelated to the average costs of the various generation technologies. Currently, infra-marginal technologies earn windfalls because the marginal price is set by expensive gas plants, while in the future renewables under the current organizational structure would suffer losses since market prices would converge towards their own marginal cost, preventing them from recovering their average costs.

Another mechanism, far less discussed, is the socio-political dynamic triggered by marginal pricing in a context where the difference in marginal costs of the participating technologies is substantial. This mechanism is likely to be triggered even before the merit order and cannibalisation effects become significant. In fact, under the current (2022) crisis of electricity price in Europe it is on full display. It is hence important to learn from the experience of the European electricity prices crisis, understanding its structural drivers and how they can replicate during the transition, so that additional barriers can be prevented.

13 *Infra-marginal producers are all those that, for a given point in time, bid below the clearing bid and hence will be rewarded at a marginal price above its marginal cost.*

1. INTRODUCTION

IRENA has been working for a decade on the organisational challenges of integrating higher shares of generation based on variable renewable electricity (VRE) into the power system. Early work focused on the challenges for liberalised power markets (IRENA, 2014, 2017). But it soon became evident that a wider approach was needed - one encompassing both liberalised and non-liberalised contexts and actively addressing misalignments so as to arrive at structures that are right for the renewable energy era. A holistic approach to the transition requires recognising its systemic nature, where various embedded systemic layers (power system, energy system, economy, society, Earth) interact to produce final outcomes (IRENA, 2020, 2022a).

Important misalignments in the power system layer stem from the marginal pricing mechanisms established during the fossil fuel era as the main procurement structure in virtually all power systems. Some of these misalignments – namely the merit order and cannibalisation effects described in the previous section – and their potential to become transition barriers have been well known for some time. Proposals to address them have ranged from adjustments to the current organisational structures to more structural changes.[14] Most of the structural proposals to address these misalignments are consistent with IRENA's proposal for dual procurement of renewable generation and flexibility (IRENA, 2020, 2022a).

To date, however, action to address these misalignments has been limited, focusing chiefly on fixes to the marginal pricing mechanism. Some of these fixes have reinforced transition barriers, such as capacity remuneration mechanisms for fossil fuel plants that risk locking in such plants for decades (IRENA, 2022a). In fact, although evidence of these misalignments has been slowly permeating the discussion, it is not until very recently that the marginal pricing mechanism itself has been questioned (ACER, 2022; DBEIS, 2022).

The prevailing policy narrative is still disconnected from the underlying misalignments. Current policy action often pursues the gradual or rapid elimination of additional regulated payments for renewable generation and encourages the development of VRE under existing (short-term) marginal pricing markets (merchant plants), despite evidence of the high relevance of long-term procurement mechanisms to support a sustainable deployment of renewables - be it through corporate or auctioned power purchase agreements (PPA) (IRENA, 2019), feed-in tariffs (FiT), contracts for differences (CfD) or others.

The high electricity prices experienced since mid-2021, driven chiefly by increases in natural gas prices exacerbated by the war in Ukraine, have opened a window of opportunity for discussing the current suitability of the marginal pricing mechanism.

The recent statement of the President of the European Commission marked a clear turning point in this respect. "This market system no longer works", said Ursula von der Leyen in early June 2022; "It was designed 20 years ago when renewable energies began to enter the mix. We ... must adapt it to the new realities of the dominant renewable energy sources".[15]

14 See, for example: (Barroso et al., 2021; Bhagwat and Meeus, 2019; Blazquez et al., 2018; Brown and Reichenberg, 2021; Batlle et al., 2021; DBEIS, 2022; Hogan, 2022; Joskow, 2019; Kanellakopoulou and Trabesinger, 2022; Keay and Robinson, 2017; Keay-Bright and Day, 2021; Nelson et al., 2017; Ofgem, 2022; Peng and Poudineh, 2017; Pototschnig et al., 2022; Robinson, 2022; Robinson and Keay, 2020; Vazquez et al., 2002).

15 See, for example: (Agence Europe, 2022; ePrimefeed, 2022; Energate Messenger, 2022; Prospero Events Group, 2022; Simon and Kurmayer, 2022).

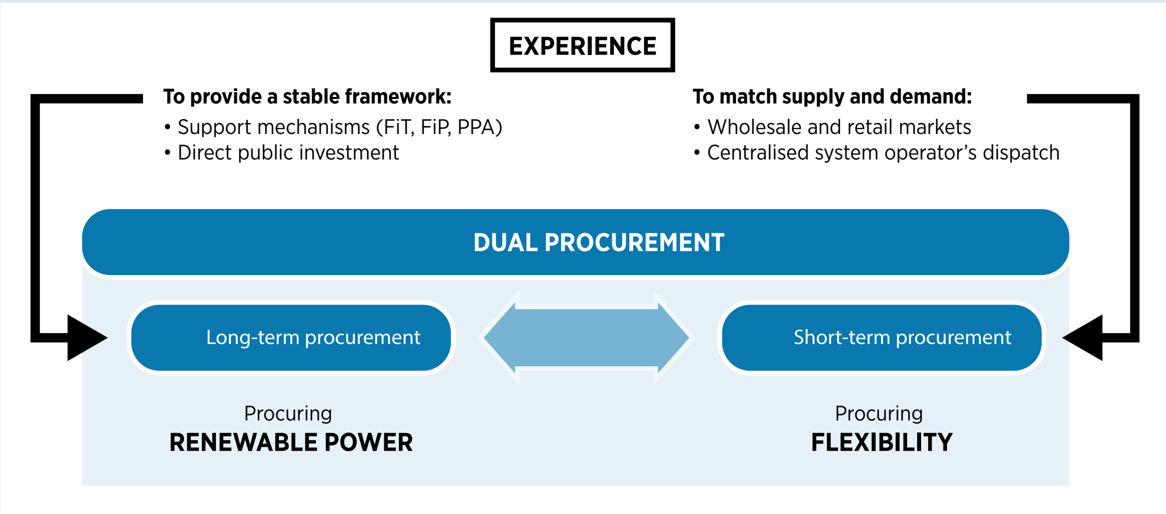
Box 1 IRENA's dual procurement proposal

One of the main sources of misalignments in wholesale electricity markets based on marginal pricing is the use of a single mechanism to procure two very different products: bulk renewable electricity and flexibility. By procuring both products using the same mechanism their different techno-economic characteristics cannot be properly honored, such that the huge difference in their respective marginal prices triggers perverse socio-political dynamics that ultimately increase the barriers to the energy transition.

In its dual procurement concept (IRENA, 2020, 2022a), IRENA addresses the source of these misalignments by proposing to split procurement of VRE and flexibility into two different but coordinated mechanisms that consider the techno-economic characteristics of both.

Under a common umbrella, dual procurement has a long-term procurement mechanism for VRE and a short-term procurement mechanism for flexibility (Figure 1). The experience accumulated in recent decades on how to provide a stable framework for VRE, and how to match supply and demand in the short term, is reflected in the pillars of the dual procurement concept.

Figure 1 The dual procurement concept

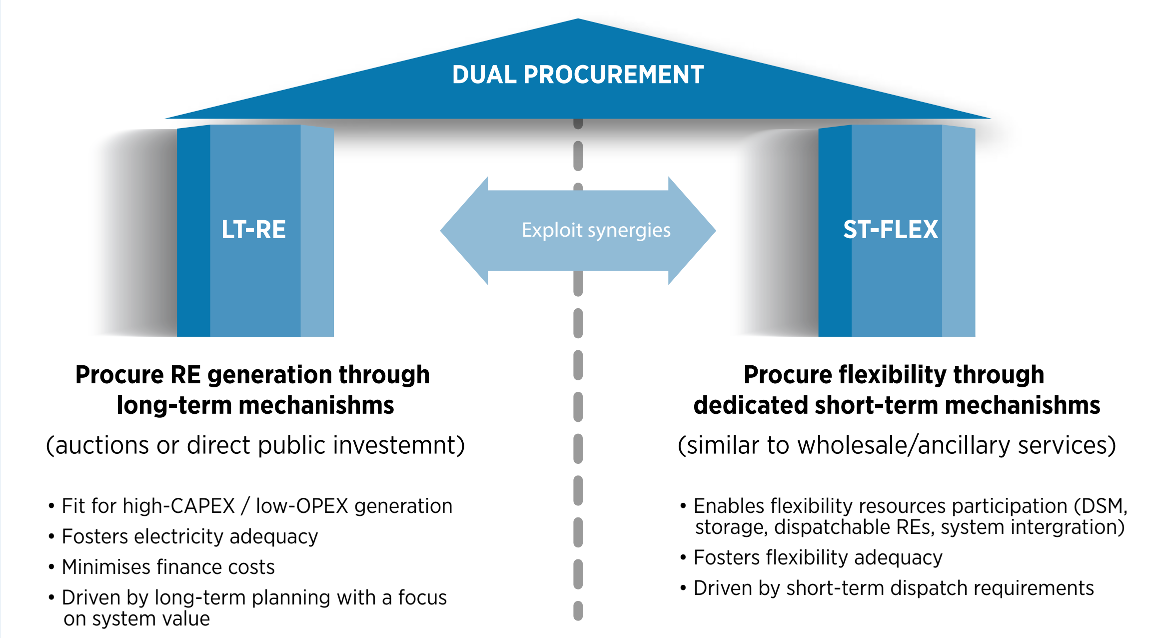


Source: IRENA, 2022b.

Figure 2 presents the characteristics of the two main pillars of dual procurement: the long-term procurement of renewable bulk electricity (LT-RE) and the short-term procurement of flexibility (ST-Flex). In specific contexts it is possible that additional procurement components (such as long-term flexibility: LT-Flex) may be needed during the transition to complement the two principal pillars.

Marginal pricing still plays a prominent role in dual procurement, being the backbone of the ST-Flex pillar; but by limiting the scope of marginal pricing to that pillar and procuring bulk renewable generation through a differentiated mechanism under the LT-RE pillar, the source of the misalignments in the current wholesale electricity markets is avoided.

Figure 2 The two pillars of dual procurement



Source: IRENA, 2022b.

Notes: LT-RE: long-term renewable electricity procurement; ST-Flex: short-term flexibility procurement; RE: renewable electricity; CAPEX: capital expenditure; OPEX: operational expenditure; DSM: demand side management; LT: long-term; ST: short-term

The mechanisms used to date to support the deployment of renewables (feed-in tariffs, feed-in premiums, contracts for differences, auctioned power purchase agreements, corporate power purchase agreements, green certificates, and so on) have been made necessary by the inability of wholesale markets based on marginal pricing to support renewables-based power systems. These mechanisms, often implemented through additional regulated payments, have been wrongly associated with subsidies for renewables, meant to disappear as the costs of renewables fall. This sort of thinking ignores or obscures the underlying misalignment. In the dual procurement proposal, the long-term procurement mechanisms become one of the main pillars of the organisational structure of the power system, making it clear that they are here to stay.

Further details are needed to adapt the dual procurement concept to different realities. See IRENA (2020, 2022a) for a full discussion.

Even with the growing acknowledgment of these misalignments, however, discussion and policy action seem to focus largely on the issue brought about by high natural gas prices (Tidey, 2022), and fail to address the remaining transition implications of these misalignments.

This technical paper aims to inform discussion and policy action around misalignments in marginal pricing, delving into the barriers that organisational structures based on marginal pricing may pose for the transition to and successful operation of a power system based on renewables. It explores how renewables can die of success (through cannibalisation and merit order effects), how price volatility may increase, and how socio-political tensions can be aggravated by the current organisational structures.

A single procurement mechanism based on marginal pricing such as the one used in today's wholesale market to procure both renewable generation and flexibility does not seem appropriate either during the transition or after it.

IRENA's dual procurement proposal (Box 1) is a step forward, providing the basis for discussion of organisational structures suitable for a power system based on renewables. Under dual procurement marginal pricing is still considered the main component of the flexibility procurement pillar. Misalignments are directly addressed by acknowledging and honouring the distinct characteristics of bulk renewable generation and flexibility, procuring each under differentiated but coordinated pillars (IRENA, 2020, 2022a).

Simplified conceptual graphs are used in this technical paper to facilitate focusing on the fundamental concepts and support an inclusive discussion. The reality of power system operation, both in the fossil fuel era and in the renewable energy era is far more nuanced. But successful organisational structures for the power sector require effective and informed socio-political involvement.

This paper addresses the characteristics of marginal pricing markets and their unsuitability for a renewables-based power system. This is done in a sequential way and illustrated by simplified graphs.

The next section forms the core of this technical paper. It focuses on the operation of wholesale marginal pricing mechanisms in the power sector and the barriers they pose for a successful and thorough energy transition. To facilitate the understanding of the source of misalignments, and how they relate with the current crisis of electricity prices in Europe, the text takes the reader through the fossil fuel era, the current spike in natural gas prices, and the transition to a power system based on renewables.

2. WHOLESALE MARGINAL PRICING IN POWER MARKETS AND ITS IMPEDIMENTS FOR A POWER SYSTEM BASED ON RENEWABLES

This section presents the sources of misalignments in wholesale marginal pricing power markets when applied to renewables-based power systems. To better understand these misalignments and how they can be expected to impact the energy transition, the reader is gradually taken from the recent past (fossil fuel era) all the way to power systems fully based on renewables, including the current (2022) price spikes due to natural gas price increases.

2.1 MARGINAL PRICING MARKETS DURING THE FOSSIL FUEL ERA AND THE EARLY PHASES OF THE ENERGY TRANSITION

Marginal pricing markets (wholesale market) have been the fundamental organisational structure for power systems in liberalised contexts for the past 2-3 decades.[16] Even in many centrally-planned contexts, marginal pricing is fundamental in the procurement of electricity.

In a marginal pricing market, the market clearing generator sets the marginal price (MP) for all the electricity produced at each point in time. The difference between the marginal price and the marginal cost (MC) (mostly OPEX) of the non-clearing generators, when accumulated over the lifetime of the plants, enables capital expenditures to be recovered and produces profits.[17] Hence, stability and predictability of the resulting marginal prices are needed to ensure sufficient investment and power system adequacy.[18]

Figure 3 presents a schematic of the operation of marginal pricing in a power system with small shares of variable renewable energy (VRE). Two operational situations are presented:

Under regular circumstances (A in Figure 3):

- Efficient base fossil fuel generation (such as combined cycle gas turbines) is the clearing technology. As such, it determines the marginal price. Because this marginal price is equal to the generator's marginal cost (mainly OPEX), it does not permit the generator to recover its CAPEX.[19]
- Less-efficient fossil fuel plants (peaking plants such as open cycle gas turbines) do not receive wholesale market payments under these circumstances because they are not needed to meet demand.

16 Of course, accompanied by strong regulatory components to guide its operation. Indeed, the theory of marginal pricing markets is far from reality, with market imperfections and externalities at play in real setups. Moreover, alignment with social value creation requires harnessing and guiding the profit motive underlying market operation. In some jurisdictions, parallel procurement structures based on long-term contracts (auctioned public or private PPAs) have evolved to cover a significant share of the demand, especially since the energy transition began.

17 The prospect of making profits is what drives investment in these plants. It should also generate economic incentives for cost reduction, efficiency, technological improvement and innovation.

18 With greater uncertainty, higher returns would be needed to trigger investment, translating into the need for higher prices to provide these returns. But since the marginal pricing mechanism that should deliver these prices is the very source of uncertainty, in an energy transition context important barriers can be anticipated, affecting the rate of deployment.

19 In any case, for these fossil fuel plants the OPEX is an important component of its overall costs.

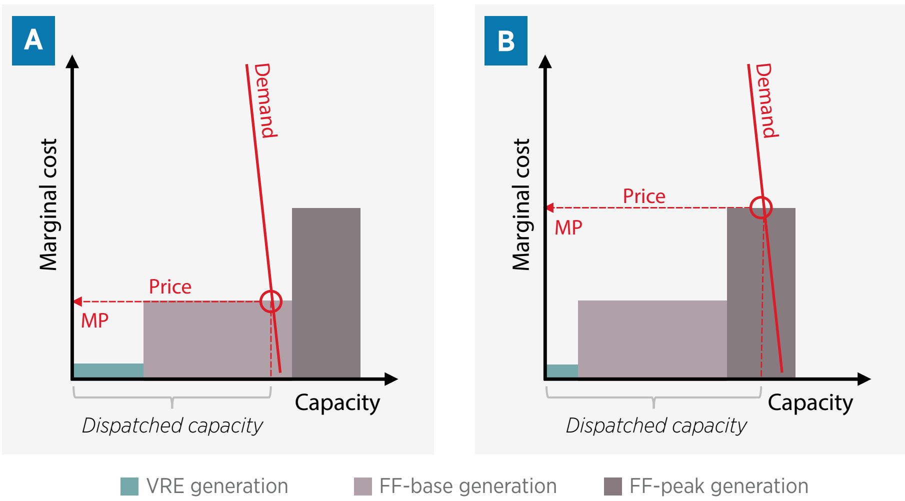
- VRE contributes to cover the demand with a very low MC.[20] Thus, if VRE participates in the market, it receives a significant differential between the MP and its MC. If the VRE does not receive additional regulated payments (it is a merchant plant), that differential between MP and MC allows these generators to recover their CAPEX.[21]

Under scarcity events (B in Figure 3), triggered either by an increase in demand, a reduction of VRE generation, or both:

- VRE and fossil fuel base generation cannot cover demand fully, and fossil fuel peak plants are included in the dispatch.
- Fossil fuel peak plants bid at a higher price in the wholesale market, because their OPEX is higher than that of base plants and they operate for a small part of the year, during which time they need to recover their CAPEX.[22]
- For fossil fuel base plants, the differential between their MC and the MP in these scarcity events makes it possible to recover CAPEX and turn a profit.
- VRE generation receives a higher differential between MC and MP, further contributing to recovery of its CAPEX and the generation of profits.

Figure 3 Marginal pricing power markets in the fossil fuel era and early stages of the energy transition (low VRE shares)

Situation under regular circumstances (A) and scarcity events (B) .



It could be said that marginal pricing makes for a rather convoluted organisational structure, since for each plant participating in the power system cost recovery is dependent on the difference between its marginal cost and the marginal price cleared by more expensive technologies and on how often these high marginal prices occur over the plant's lifetime.

When differences between plants' marginal costs are high (such as between fossil fuels and VRE), this organisational structure is also likely to trigger complex socio-political dynamics that can ultimately compromise the proper operation of the system. For instance, the fact that VRE with very low marginal cost is rewarded at a marginal price much higher than their marginal cost can unleash socio-political unrest. Communication plays a huge role in these dynamics.

20 *The MC can become even negative if these plants are receiving additional regulated payments outside the wholesale market, such as FiP or green certificates. In the early stages of use of VRE in power systems, the LCOE of VRE plants was high, and hence they received regulated support (FiT, PPA, subsidies…). VRE generation had priority of supply and hence was exogenously introduced in the dispatch.*

21 *For VRE its overall cost structure is strongly dominated by its CAPEX (relatively very small OPEX).*

22 *To avoid very high bids from these marginal plants (above their O&M), the wholesale marginal pricing market should be complemented with CRM.*

Furthermore, if the government's messaging tends to equate the marginal cost of VRE as bid in the wholesale market with its LCOE, people may have a hard time understanding why they do not benefit more from these low marginal costs and why these apparently high profits are allowed to flow to VRE plant operators.[23] This, in turn, can lead (and has led) to policy action to curtail windfall profits for VRE generators,[24] increasing the unpredictability of how this organisational structure rewards new investments in VRE generation capacity, just when a significant increase in these investments is needed to address the climate challenge.

2.2 IMPACT OF SPIKES IN NATURAL GAS PRICE (LATE-2021 THROUGH EARLY-2022 AND BEYOND)

Figure 4 presents a simplified version of the change in wholesale power prices owing to a spike in fossil fuel prices such as that experienced in late 2021 and early 2022. Under these conditions, when fossil fuel plants are the clearing generators,[25] marginal prices of electricity rise significantly, reflecting the higher OPEX of fossil fuel plants, both under regular circumstances ('A' in Figure 4) and scarcity events ('B' in Figure 4).[26]

For generators using technologies operating on natural gas:

- If the natural gas they use has been purchased at the current high prices, the higher electricity prices reflect higher OPEX; hence profits are similar to those earned under lower gas prices (Figure 3 and 'O' in Figure 4).
- If they operate using natural gas purchased earlier at lower cost (on either physical or financial markets using forward/futures contracts), what drives their higher bids is the opportunity cost of using that gas at its current prices. Hence its profits increase.

For VRE generators (and other non-clearing technologies whose opportunity cost is not affected by natural gas price increases):

- The difference between its marginal cost and the marginal price widens.
- If under lower natural gas prices (Figure 3) the differential between marginal price and marginal cost was enough to recover its total costs (OPEX and CAPEX) plus planned profits, the increase in natural gas prices (Figure 4) produces temporary windfall profits for these plants.
- But if under lower natural gas prices (Figure 3) the differential between marginal price and marginal cost was insufficient to recover total costs (OPEX and CAPEX) plus anticipated profits, the increase in natural gas prices (Figure 4) improves cost recovery for these plants.
- Therefore, this situation improves the business model of investors in VRE. The improvement can be justifiable from a social perspective[27] (if at the natural gas prices of Figure 3 total costs and benefit margins were not recovered), or not justifiable (speculative) if total costs and profit margin were already being recovered at lower natural gas prices (Figure 3). Often, the default policy response is to assume

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23 *Even today, part of the VRE installed capacity has sold forward its electricity generation through public or private (corporate) PPAs and hence does not realise extra profit from high marginal prices, and contributes to overall price stabilisation. This is precisely what IRENA's dual procurement proposal does – but systematically rather than exceptionally (Box-1, IRENA [2020, 2022a]).*

24 *Without taking into account that windfall profits are the other side of the coin of under-remuneration at other times; what matters is the balance between the two over the lifetime of the plants.*

25 *It should, however, be noted that natural gas plants are not necessarily the clearing price technologies under these circumstances, because this situation opens the door to speculative behaviour by other market participants. For instance, operators of dispatchable renewable energy technologies (DiRE) - such as reservoir-fed hydropower - that also operate natural gas power plants, do have full details of the marginal costs from natural gas-fired plants and have a lot to gain by bidding hydro generation at a marginal cost just below that of gas-fired plants. Indeed, if natural gas plants are dispatched, the marginal price would be the same, but the profit margin for these operators would be small because they have to bear the burden of the high natural gas prices. However, if they manage to substitute gas-fired generation with hydro generation while keeping essentially the same marginal price linked to the marginal cost of natural gas plants, their profit margin widens substantially. For instance, when in early March 2022 wholesale electricity prices in Spain approached 700 EUR/MWh, the clearing technology was sometimes hydro generation with a marginal cost of 3 EUR/MWh at fully amortised plants.*

26 *An additional effect of this price increase is a reduction in electricity demand, represented in Figure 4 by a decrease of total dispatched capacity. Under rather inelastic electricity demand as that represented in Figure 4, this effect is small, but under more elastic demand the reduction in total dispatched capacity would be higher.*

27 *That is, if the improvement brings a rate of return on investment commensurate with the risks taken.*

that VRE generators' higher revenues is unjustified (from a social perspective) and to introduce legislation or regulations to curtail the assumed windfall profits, ignoring the question of whether the wholesale market and its marginal pricing was (under lower natural gas prices) providing the right signal to VRE investors to deploy all the capacity needed to address the climate challenge.[28] This asymmetry – with policy makers failing to see and acknowledge the past and future shortcomings of the current organisational structure with respect to the technologies needed for the transition, but being quick to react against isolated increases in returns – is likely to create impediments to the transition.

- Therefore, it may be concluded that the current situation in the wholesale market with very high natural gas prices need not, in and of itself, constitute a transition barrier. To the contrary, it could stimulate further investment in VRE and other transition technologies.[29] However, a transition barrier arises as a consequence of the resulting socio-political dynamics. Misguided policy action (i.e. castigating VRE for reaping windfall profits) may increase regulatory uncertainty and make it more difficult for VRE generators to recover their costs, and reduce the social licence for VRE deployment, thereby impeding the transition. Moreover, high natural gas prices within a non-'transition proofed' socio-political context could[30] stimulate additional private and public investments in natural gas extraction and natural gas infrastructure,[31] thereby crowding out investment resources from the deployment of renewables and sustainable flexibility and locking-in additional fossil fuel infrastructure for decades.

For electricity users:

- Electricity prices increase significantly unless targeted policies are introduced to dampen and dilute this direct impact. Subsidies for producers or users must ultimately be passed along to users through taxes, although with the possibility of redistribution of impacts. Electricity price increases may also hamper investments in end-use equipment (electric vehicles, heat pumps,…), thereby impeding electrification of the energy system and raising yet another barrier to the transition.
- Proper communication is essential to prevent events like such natural gas price spikes from creating social impediments to the transition. If policy makers propagate the image of VRE producers receiving windfall profits and the myth that VRE has very low costs for the user, without making clear that marginal cost bids in wholesale markets do not reflect the dominant component of the VRE cost structure (CAPEX), this could set in motion a dynamic wherein investment in VRE falls behind the needs of the energy transition.[32] Social approval for VRE deployment requires clarity on the question of whether windfall profits are being generated. The necessary clarity becomes difficult when comparing the situations in Figures 3 and 4: either in Figure 3 (former natural gas prices) VRE facilities were not being properly rewarded to cover their costs, or in Figure 4 (current natural gas price spikes) they are reaping windfall profits.

28 One example of regulatory asymmetries in handling VRE generators' revenues would be one-sided/asymmetric contracts for differences (CfD), where VRE generators must return revenues above a marginal price threshold but are not compensated when marginal prices fall below the specified threshold. The focus should be on life-cycle revenues; in this sense higher and lower revenues are two sides of the same coin that ideally should compensate each other over the economic lifetime of the facility.

29 Despite this higher differential between marginal price and marginal cost, the marginal pricing mechanism would still fail to provide the long-term certainty needed to unlock the required investment in VRE. The long term renewable energy pillar in the dual procurement proposal (Box 1, (IRENA (2020, 2022a))) aims to provide a definitive and stable response to this reality that to date has been provisionally addressed through regulated payments such as feed-in tariffs, contracts for differences and power purchase agreements.

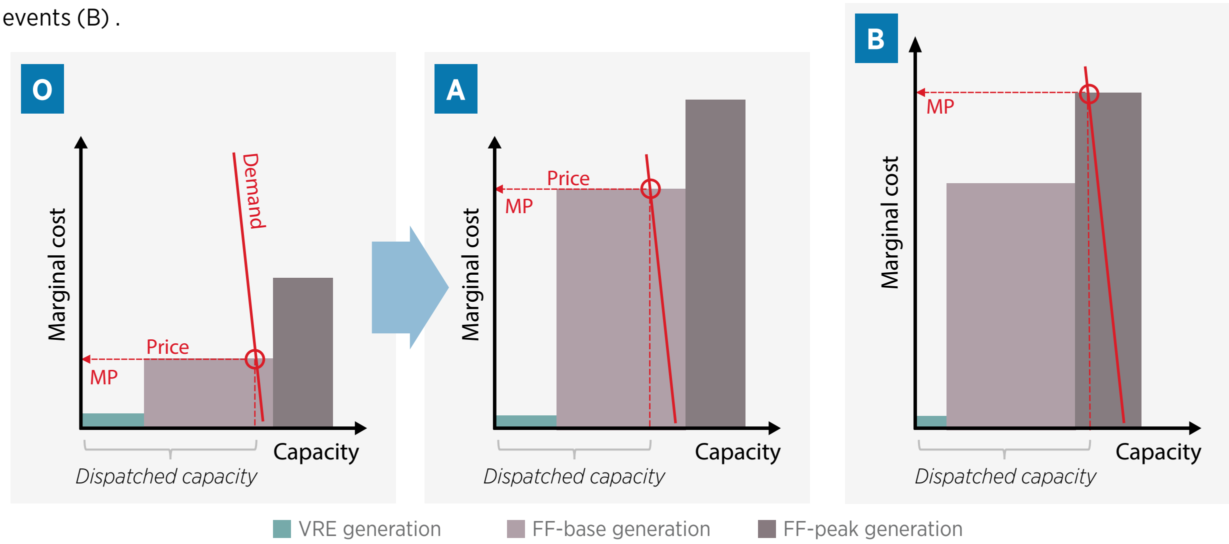
30 Indeed, this is already happening. It has gone as far as the EU declaring natural gas as green and sustainable energy in its taxonomy (early July 2022), and momentum building up for African countries to use its natural gas domestic resources to advance its economic development within a transition context.

31 Such as Liquified Natural Gas (LNG) terminals and storage facilities and natural gas pipelines.

32 See also the cost-price-value misalignment discussions in IRENA (2020, 2022a) for a better understanding of how the 'rise to the bottom' in costs and prices is often not the best approach to value creation.

Figure 4 Marginal pricing markets affected by fossil fuel price spikes

Situation before the price spikes (O); situation after the price spikes under regular circumstances (A) and scarcity events (B) .



In any case, it is clear that the widening difference between the marginal costs of participating technologies under natural gas price spikes and those prevailing in the original situation when VRE started to enter the power system, exacerbates the problematic socio-political dynamics linked to the marginal pricing mechanism.

This is a direct consequence of the marginal pricing organisational structure itself, and it would take very good analysis, communication and policy to gain the social license to reward VRE generation at such high marginal prices compared with its marginal cost ('A' and 'B' in Figure 4). Experience has shown that the communication and policy skills needed to deal with this situation may not be available. Therefore, high differences in the marginal costs of the technologies participating in the wholesale market based on marginal pricing runs the risk of inducing problematic socio-political dynamics that may raise transition barriers or even endanger the operation of a power system based on VRE.

However, high differences in marginal cost are not limited to the current natural gas price spikes crisis. An analogous situation may be encountered during the transition and after the transition (Figure 5).

Indeed, the current increases in marginal prices for wholesale electricity are analogous to what would follow if the externalities of fossil fuel generation were properly internalised.[33] Introducing a higher carbon price would have the same effect as increases in natural gas prices (C in Figure 5). In fact, in late 2021 and early 2022, before the onset of the war in Ukraine, increases in the marginal price of wholesale electricity in Europe were driven by a combination of rising natural gas and carbon prices. In March 2022 this situation was exacerbated by further increases in natural gas prices owing to the war in Ukraine, but current carbon prices are still very low compared to those that would be needed to address the climate challenge.

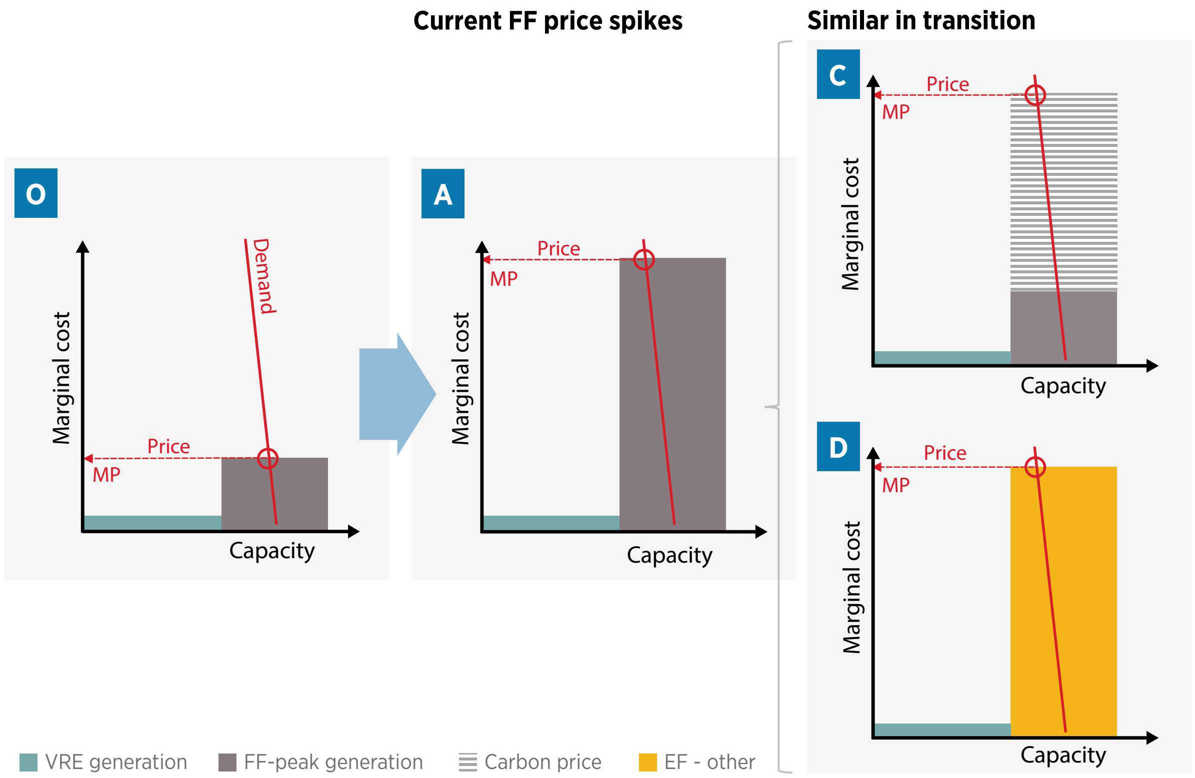
33 *Carbon pricing in power system markets has been proposed as an option to prevent the 'missing money' problem the VRE experiences as its shares grow during the transition (Brown and Reichenberg, 2021). The point of introducing a carbon price is to make fossil fuel technologies less competitive and hence facilitate their displacement by renewables in a liberalised context. However, in a marginal pricing structure there would be a second direct effect of carbon pricing: to increase the difference between the marginal price and the marginal cost of inframarginal technologies (such as VRE), hence incentivising its deployment and compensating for the cannibalisation and merit order effects (missing money). In light of the current experience of high natural gas prices on electricity prices, care should be taken to manage the socio-political dynamics that might lead to actions to curtail additional profits for VRE generators (often interpreted as windfalls). Beyond the challenges posed by such socio-political dynamics, basing the deployment of renewables in the power sector on carbon pricing and marginal pricing markets could prove problematic during the transition (e.g. because of the need to continuously increase carbon prices as the clearing hours of fossil fuel technologies fall with the deployment of renewables) and leave the renewables-based power system exposed to an inappropriate structure once fossil fuels are phased out and carbon pricing no longer affects the marginal price.*

Indeed, at a natural gas price of 100 EUR/MWh,[34] it would take a carbon price slightly above 300 EUR/tCO_2 to reach marginal costs of 300 EUR/MWh at a combined cycle power plant.[35] Even under the natural gas price cap for power generation in the Iberian exception[36] (Tidey, 2022), a carbon price slightly above 550 EUR/tCO_2 would be needed to produce electricity prices of 300 EUR/MWh. These levels of carbon pricing (300-550 EUR/tCO_2) are well within those needed to accelerate and complete the energy transition. Therefore a situation similar to the one that led to the electricity price crisis in Europe (A in Figure 5) could occur as we press on with the transition under the present organisational structure based on marginal pricing (C in Figure 5).[37] Moreover, a similar situation can be expected once the transition is complete if we insist in procuring all VRE generation and flexibility under the same marginal pricing market (D in Figure 5), since the flexibility resources will be pressed to bid at very high marginal cost in order to recover life-cycle costs over just few hours of operation (assuming the absence of additional capacity remuneration mechanisms).

The situation in Europe's electricity markets, which is the consequence of very high natural gas prices, has attracted a great deal of attention both from policy makers and the general public, which opens a window of opportunity to address structural issues with the current power system organisational structure. However, both policy makers and citizens (as a consequence of how the issue has been communicated to them) have placed nearly exclusive emphasis on lowering prices, failing to identify the structural pitfalls that can produce transition barriers.

Figure 5 Growing difference in marginal cost of technologies participating in wholesale electricity market

Before the natural gas price spikes of 2021-2022 (O); during the spikes (A); if the carbon price were increased to accelerate the transition, while recovering natural gas prices from before the spike (C); and if flexibility were procured using the same marginal pricing mechanisms as bulk VRE generation (D).



34 Which is significantly lower than prices experienced in March 2022, that reached 230 EUR/MWh.

35 300 EUR/MWh is the level of high electricity price that was regularly experienced in Spain during early 2022 and that sounded socio-political alarms.

36 Proposed by the Spanish and Portuguese governments (early April 2022) at 30 EUR/MWh, accepted by the EU at 50 EUR/MWh in May 2022, and applied since June 2022 at 40 EUR/MWh.

37 Unlike the high natural gas prices of 2022, the introduction of carbon prices leading to similar marginal prices of wholesale electricity would not incentivise additional investments in natural gas infrastructure, as the natural gas price spikes are doing in 2022.

2.3 WITH INCREASING PENETRATION OF VRE

As the energy transition advances, the share of VRE in the power system increases. That rising share triggers several dynamics that may raise transition barriers.

With an increasing share of renewables, lower bids clear the market, reducing the marginal price. This means that the differential between the marginal cost of VRE (its OPEX) and the cleared marginal price shrinks, and with it the capability of VRE generators to recover their CAPEX and produce profits. Over time, this will erode the business case for VRE, slowing down or halting its deployment.[38]

Growing shares of VRE in the power system reduce the volume of electricity dispatched by fossil fuel plants. This, together with the marginal price depression mentioned above, decreases annual revenues for fossil fuel plants, potentially preventing them from recovering their LCOE. This triggers requests for additional payments (such as capacity remuneration mechanisms), which in turn can entrench fossil fuel generators into the power system, slowing down the deployment of non-fossil fuel flexibility.

Regarding the merit order and cannibalisation effects, increases in the price of natural gas and/or increases in carbon prices could reduce these effects to some extent – and might even neutralise them entirely.[39] Indeed, as shown in Figures 4 and 5, increases in natural gas and/or carbon prices result in a larger differential between the marginal price and the marginal cost of VRE, thereby increasing the capability of VRE facilities to recover their CAPEX.

With the appropriate differential between marginal price and marginal costs this could be true even if the number of hours during which fossil fuel technologies clear the market drops as VRE shares increase. In fact, a gradual increase of natural gas and carbon prices as VRE shares increase could theoretically compensate the merit order and cannibalisation effects until very large shares of VRE are achieved.

However, as mentioned above, the problem with such high prices goes beyond their immediate impact on consumers. The substantial difference in the marginal costs of the plants participating in the marginal market brings about a socio-political challenge. Exacerbated by poor communication about (and understanding of) how the marginal market works, and pressures from some incumbents, high prices cleared by fossil fuel electricity can easily[40] trigger policy action to curtail what are seen as the 'windfall profits' of VRE generators, insisting on the wrong narrative of linking the potential for low electricity prices from VRE to its low marginal cost bids in the wholesale market, thereby potentially killing the mechanism neutralizing the merit order and cannibalisation effects, and hence introducing transition barriers.[41]

Large differences in marginal costs across participating technologies make it difficult to strike a balance among 1) enabling VRE deployment, 2) preventing undue windfall profits and 3) gaining social licence for proceeding with the transition at the required pace. The source of such challenges is the prevailing organisational structure based on marginal pricing, highlighting the need to explore other options better suited for the transition.

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38 To address this issue (and protect users against price volatility), the dual procurement proposal (Box-1) makes the long-term procurement of renewables one of the main pillars of the power system's organisational structure. Corporations are already following this approach through corporate PPAs. The dual procurement proposal would extend these benefits to the entire power system.

39 However, the larger the VRE share, the smaller the neutralising effect of higher costs in fossil fuel generation (increased fossil fuel costs or carbon prices). When 100% of the load is covered by renewables (as already seen in certain jurisdictions and periods), higher costs of fossil fuel generation have no impact on the resulting marginal price.

40 As it has recently happened.

41 The goal of a generator is at minimum to recover life-cycle costs (and, for profit-driven investments, to meet profit targets). This calls for a life cycle vision in which today's windfall profits could be the piece that compensates tomorrow's underpayments due to merit order and cannibalisation effects.

2.4 POWER SYSTEM BASED ON VRE (SIMPLIFIED)

Eventually, as VRE capacity increases, it will completely displace fossil fuel plants from the market, phasing them out by the end of the energy transition (Figure 6).[42]

Under these circumstances, since the clearing generator will be VRE with very low marginal costs, the marginal price will be very low (in fact almost zero). This is the idealised outcome that has been implanted in the public imagination by policy narratives about how low are VRE marginal cost bids in the wholesale market. The problem is that this situation is unsustainable. Indeed, at such low marginal prices, VRE generators will be unable to recover their CAPEX (the dominant component of their price structure), let alone turn a profit. Once this happens, the business case for investing in VRE will evaporate.

The impact would likely be felt before the transition is complete. When investors forecast revenues over a plant's lifetime, they would perceive a very high risk of not recovering their investments. This would significantly increase financing costs, eliminating any prospect of a low LCOE and slowing VRE deployments and the completion of the energy transition.

But assuming a complete transition in which VRE meets nearly all demand ('A' in Figure 7), electricity price volatility and compromised system adequacy would erode reliability. Figure 7 shows how this could play out. It splits the VRE used to meet demand into three groups of plants with similar technical and economic characteristics.

At the starting point ('A' in Figure 7) all VRE bids are at marginal cost,[43] leading to a very low marginal price. No VRE generator would be able to recover its CAPEX, let alone to turn a profit. The existing VRE plants would go bankrupt, since the revenues provided by the marginal price market would be much below whatever provision they had in their business case.[44]

Still, due to their low marginal cost, these plants would likely keep operating until the end of their useful lifetimes, since any revenue they could earn from the wholesale market would be better than no revenue at all. This would likely lead VRE generators to pressure governments to reintroduce additional regulated payments such as feed-in tariffs, contracts for differences and power purchase agreements.[45] This is already happening for fossil fuel plants that have seen their business case eroded because of reduced operating hours. In any case, such a setup, with temporary fixes that failed to address the root cause of the existing misalignment, would eliminate any incentive for future investments in VRE generation because of the unfeasibility of producing any sound business case based on the marginal wholesale market revenues and the uncertainty of regulation and policy action. It would also reduce system performance and reliability because of the low maintenance consequence of reduced income. System adequacy would fall as the existing VRE plants reached the end of their useful lifetimes.

Once a block of VRE generation reaches the end of its lifetime (B in Figure 7), the existing VRE capacity would be unable to meet[46] the full load served under A (in Figure 7), placing the power system in a position of continuous scarcity.

42 *The technical and economic feasibility of power systems based entirely on renewables has been demonstrated (Aghahosseini et al., 2020, 2019; Garcia-Casals, 2011, 2006, 2005; Jacobson et al., 2017; Ram et al., 2019, 2018, 2017), and in most cases the bulk of generation in these power systems comes from VRE.*

43 *Because of the excess in VRE capacity, none of the plants would bid above their marginal cost (in effect their O&M costs), because doing so would exclude them from dispatch and they would receive no remuneration.*

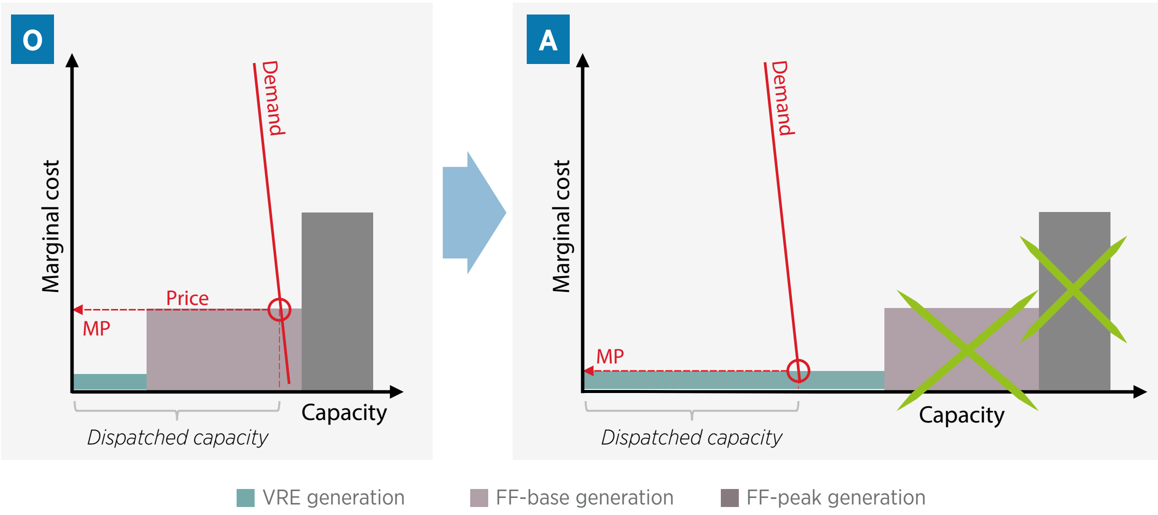
44 *If these plants had been developed using project finance, the business model used for its finance would have forecasted (based on higher wholesale market prices) a revenue flow sufficient to service the debt and produce profits.*

45 *Introducing these regulated payments would conceptually be equivalent to moving towards the long-term renewable electricity procurement (LT-RE) from the dual procurement structure.*

46 *Note that here comes to play another characteristic of VRE generation: its incapability to increase generation above what the natural resource (wind or sun) provides. This means that although VRE plants operate with low capacity factors (20–40% for wind; 15–30% for PV), it is not feasible to increase this capacity factors to cover the unmet load.*

Figure 6 VRE deployment displacing FF generation on a marginal pricing market (simplified)

Situation before the price spikes (O); situation after VRE has displaced fossil fuel generation (A).



Under these circumstances, the last VRE block in the merit order curve would be able to significantly raise its bid up to the price users would be ready to pay at this level of overall load, producing a significantly higher marginal price. How high would depend on the inelasticity of demand. The OPEX from this VRE block would be the same as before, but its opportunity cost would rise and drive its marginal cost because of the deficit in recovering CAPEX through the wholesale marginal market.[47]

The resulting marginal price would improve cost recovery for all VRE generators. However, the 'invisible hand' of the market cannot work magic: The resulting marginal price might be higher or lower than the one required to recover the costs of VRE generators. If it were higher, VRE generators would earn windfall profits; if lower, they would be unable to recover their CAPEX.[48]

On top of this endogenous instability, it could be expected that misguided policy action, caused by an incorrect understanding of how marginal markets work or by a rebound from populistic[49] messages sent to citizens, would exacerbate the situation by reclaiming imaginary[50] windfall profits from VRE generators under B (in Figure 7).

If the net result of this turbulent dynamic were that the higher marginal price in B (Figure 7) enabled full cost recovery and profits for VRE generators, this would trigger investments in additional VRE capacity. With enough VRE capacity to cover all demand, generators' bids would once again reflect low marginal costs based on low OPEX. Hence the original situation would be recovered with very low clearing marginal prices and higher demand being met ('A2' in Figure 7).

Hence, the resulting dynamics could lead to volatility in price and served load, with both oscillating[51] over VRE investment cycles (see the bottom part of Figure 7), leading to low overall system adequacy and reliability, and a regressive power system able to provide secure supply only to users capable of paying high prices.

47 *In less liberalised systems, generators are not allowed to bid, and the merit order curve is produced by the system operator on the base of declared and supervised costs (cost-based market design). In this context, an LCOE-based merit order curve would also be an option.*

48 *Until additional VRE capacity reaches end of its lifetime and higher marginal prices are allowed for lower demand because of the increased scarcity (further reduction in the capability to serve the load).*

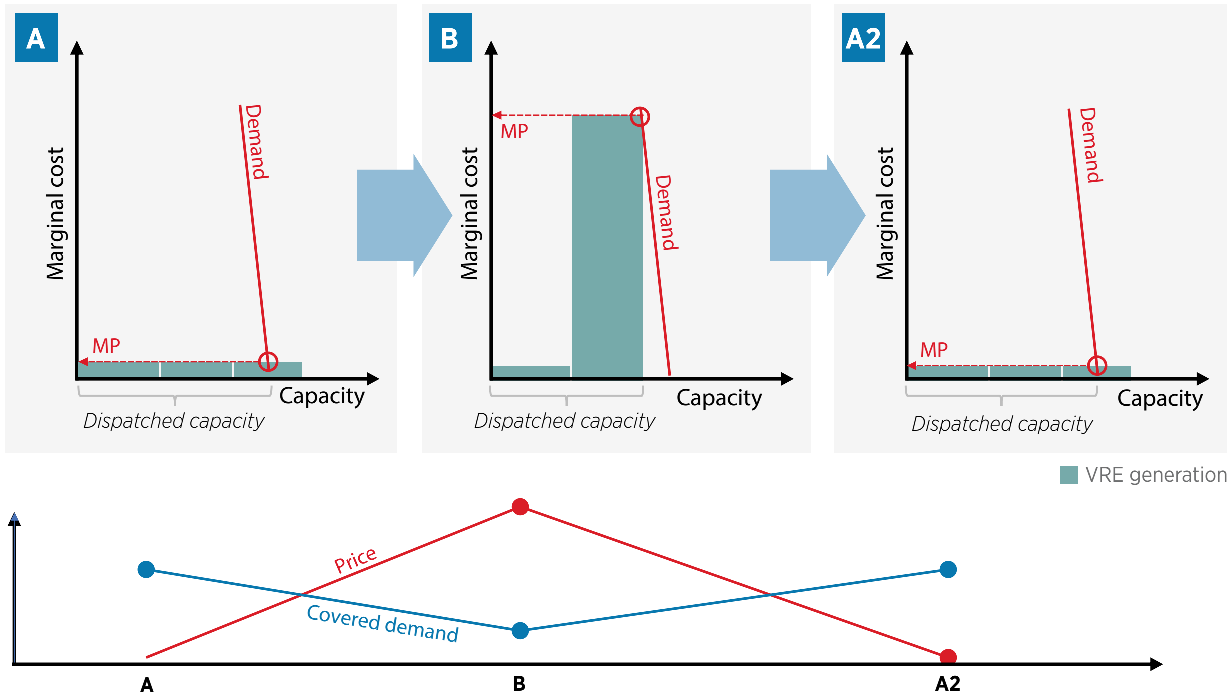
49 *i.e., that low marginal costs of VRE means extremely cheap electricity will be available under the wholesale market.*

50 *Imaginary in the sense of not looking at the life-cycle consequences, balancing these high revenues with the periods of lower than needed revenues: Under marginal pricing mechanisms applied to a RE-based power system excess revenues of inframarginal plants at some points in time and missing money issues at other points in time are two sides of the same coin, which makes it socio-politically complex to manage.*

51 *The greater the demand elasticity, the less the price oscillation and the greater the served demand oscillation.*

Figure 7 Marginal pricing market operating in a VRE power system (simplified)

Situation after completing the transition when demand is met by enough VRE capacity (A); Situation with scarcity of VRE capacity driven by the incapability to recover costs under A (B); Situation of excess VRE capacity driven by the high marginal prices during the scarcity period in B (A2).



This situation could theoretically be avoided if VRE generators were to bid at their LCOE instead of their marginal cost.[52] However, owing to the very low marginal cost for these plants, in a market with many participants it might be impossible to guarantee a stable bidding behaviour at LCOE. Indeed, once a VRE plant is built, owing to its low OPEX, owners would prefer to be included in the market clearing even at prices below LCOE than to be left out of the dispatch and receive no revenue at all. Hence, generators – knowing they would be left out of dispatch at any point in time because of their higher LCOE – would have a strong incentive to offer bids below their LCOE. Since all VRE generators share the characteristic of extremely low OPEX, this behaviour would trigger a 'race to the bottom'[53] with all VRE generators bidding at their O&M costs and hence recovering the situation presented in Figure 7.

2.5 POWER SYSTEM BASED ON VRE (MORE NUANCED)

A power system based on renewables is more complex than what has just been described.

Indeed, for a power system based on VRE to work, flexibility is a fundamental pillar. In such a power system, flexibility would be supplied by dispatchable renewable generation (*i.e.* hydro with reservoirs, CSP, biomass and geothermal power), as well as other flexibility resources (such as demand-side response, storage and energy-system integration).

Under the current wholesale power market based on marginal pricing, both VRE bulk electricity generation and flexibility would be procured simultaneously using the same mechanism. Figure 8 presents a graphical representation of this arrangement.

52 The LCOE bid would have to be a dynamic LCOE modified over time with the forecasts of curtailment along the lifetimes of the plants. Bidding at the LCOE thus construed would be conceptually very similar to the long-term procurement of renewables (LT-RE) from the proposed dual procurement structure (for instance, auctioned power purchase agreements), but with all the operational instabilities associated with using an unfit organisational structure (marginal market operated with life-cycle costs).

53 These "race to the bottom" dynamics are already being fostered today in some jurisdictions, even reaching negative bidding procurement - which is absolutely unsustainable.

With very large VRE shares in the system, demand would be often fully supplied by VRE ('A' in Figure 8). The low marginal cost of VRE generators would produce a very low clearing marginal price. All dispatched VRE generators would receive this marginal price, which would not cover total costs (dominated by CAPEX). The non-dispatched VRE, dispatchable renewable energy and other sources of energy flexibility would get no market reward as long as the market is cleared as per 'A'.

At times when VRE generation is reduced (amid low availability of solar or wind resources) or demand increases, dispatchable renewable energy (DiRE) would have to be dispatched ('B' in Figure 8). The higher marginal cost of DiRE would set a higher clearing marginal price (the dispatchability of DiRE increases its opportunity cost). VRE would thus see a differential between this marginal price and its marginal cost, allowing partial recovery of CAPEX. But this recovery is likely to be limited because the volume of electricity dispatched by VRE under these circumstances would be small (*e.g.* due to limited solar or wind resources). The non-dispatched share of DiRE and all other sources of energy flexibility would obtain no reward from the market under these circumstances.

At times when VRE generation is further reduced or demand increases, other energy flexibility resources would have to be dispatched (C in Figure 8). These circumstances would produce a higher marginal price driven by the high marginal cost of the flexibility technologies used for clearing. The differential between this high marginal price and the marginal cost of VRE and DiRE would contribute to their CAPEX recovery. Sources of energy flexibility beyond demand-side management options with low CAPEX requirements would be dispatched only a few hours a year. They would have to be bid out at a marginal cost well above their OPEX in order to recover their CAPEX, which can be high for some of these technologies (such as storage).

In theory, such a setup could work for a power system based on renewables, just as today's marginal pricing markets have worked during the fossil fuel era, though the fact that cost recovery would be achieved in very small windows of time would likely trigger instability. Yet the fundamental misalignment embedded in this scheme – procuring two very different products (VRE bulk generation and flexibility[54]) under one common procurement mechanism based on marginal pricing – could be problematic, potentially evolving into issues of power system adequacy and reliability.[55]

The socio-political dynamics triggered by a large difference in the marginal cost of the technologies participating in this marginal pricing market would be on full display, as technologies with low marginal cost (such as VRE) are compensated at a very high marginal price whenever flexibility resources need to be dispatched. The perceived risks of these socio-political dynamics would likely push up finance costs, leading to underinvestment (with the attendant gap in system adequacy) and higher overall electricity costs.

This misalignment would affect both VRE generation and sources of energy flexibility, since using a single structure to procure these two very different products makes it impossible to honour either one properly. Hence multiple transition barriers could be expected, with important feedback loops, ultimately resulting in lower deployment of VRE and energy flexibility than required (the lack of adequate energy flexibility resources would further hinder VRE deployment).

The operation of the system illustrated in Figure 8 is rather similar to the one that is being experienced in 2022 as a consequence of high natural gas prices (see Figure 4, Figure 5), with the high difference in marginal costs of the technologies participating in the wholesale market driving the resulting dynamics.[56] As a consequence of poor understanding and miscommunication regarding how the marginal market works, the large difference in marginal cost between VRE and fossil fuel-based generation (2022 with high natural gas prices) in Figure 4, or VRE and flexibility resources in Figure 8, is likely to trigger a negative social reaction (exacerbated

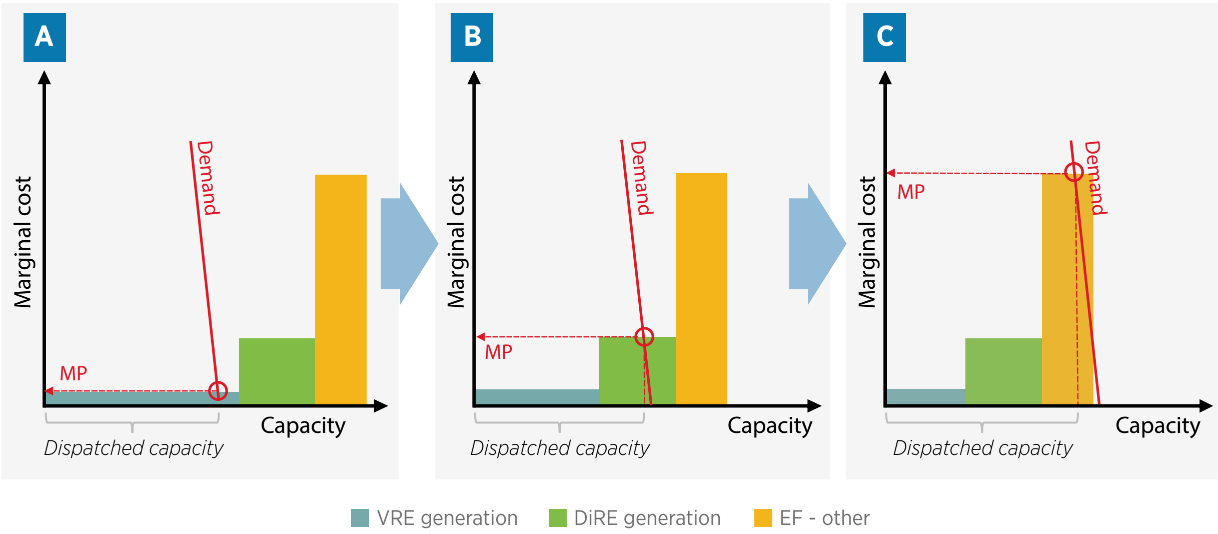
54 The procurement structure in this setup is even worse than shown in Figure 8 because flexibility requirements in a renewables-based power system are call for both upward and downward regulation, whereas Figure 8 captures only the upward case.

55 In a VRE-dominated system, the goal of the mechanism used to price bulk VRE generation should no longer be the selection of generators with the lowest short-term operation costs.

56 The fact that in the marginal wholesale market all dispatched technologies are rewarded at the cleared marginal price set by the most expensive technology becomes socio-politically problematic when some of the dispatched technologies have very low marginal costs and are rewarded at very high marginal price.

Figure 8: Marginal pricing market operating in a VRE power system (more nuanced)

Most common situation when VRE generation can supply all the demand (A); Situation when meeting the demand requires both VRE and DiRE (B); Scarcity situation when other EF is required to participate complementing VRE and DiRE in order to supply all demand (C).



by inappropriate policy messaging).[57] What has already been experienced of this dynamic in the wake of natural gas price spikes offers a strong argument for using an organisational structure that it is well suited to the characteristics of both VRE and energy flexibility resources. The dual procurement system proposed by IRENA (2020, 2022a) meets this requirement.

57 *During the fossil fuel era (Figure 3) this situation did not occur because of the similar marginal costs of all participating technologies (there were no dominant technologies with almost zero marginal costs such as VRE).*

3. CONCLUDING REMARKS

The conceptual discussion presented in this technical paper documents why wholesale electricity markets based on marginal pricing do not seem an appropriate organisational structure for renewables-based power systems, during or after the transition.

During the transition, and under circumstances of high fossil fuel and carbon prices, power markets based on marginal pricing may favour investors in variable renewable energy (VRE), since under such circumstances investors would enjoy a large differential between high marginal prices and the low marginal costs of their investments. However, that gap, underpinned by poor understanding and communication about how marginal markets work, can invite socio-political instability, raising perceived risk – and thus financing costs. The net result may be that capacity deployment will fall short of the levels needed to complete the transition and protect the climate. When fossil fuel and carbon prices are low, the merit order and cannibalisation effects will negatively affect VRE developments by raising perceived risks about cost recovery owing to the resulting price depression. On top of that, the reducing revenues for incumbent fossil fuel generation are likely to amplify transition barriers through, for instance, the introduction of capacity remuneration mechanisms that entrench fossil fuel capacity into the system.

Once the transition is complete (yielding a power system based entirely on renewables), marginal pricing could hinder and compromise the reliable operation of the power system. Indeed, the socio-political instability described above and witnessed during 2022 natural gas price spikes will also be at play, since its fundamental driver (a large difference between marginal prices cleared by flexibility providers and very low marginal costs of VRE) will be present. On top of that, under regular operating conditions, merit order and cannibalisation effects will occur, with the cleared marginal price being too low to recover CAPEX and generate profits. The resulting high uncertainty about costs recovery could lead to underinvestment and damage power system adequacy. The very prospect of this situation is enough to introduce barriers that will hinder the energy transition.

These misalignments stem from the use of an organisational structure with one single mechanism (marginal pricing wholesale market) to simultaneously procure two products (bulk VRE generation and flexibility) having very different techno-economic characteristics and procurement requirements.

IRENA's dual procurement proposal – that is, the use of two different but related mechanisms to procure both VRE bulk electricity and flexibility – attempts to address this and other misalignments in the current power system operational structure, advancing the discussion about how to transition to organisational structures suitable for renewables-based power systems.

This technical paper has focused on markets (liberalised contexts) for ease of communication. However, the concepts discussed and the conclusions presented apply in both liberalised and non-liberalised contexts. See (IRENA, 2022a) for a more inclusive discussion.

Completing the energy transition is urgent (IRENA, 2022a). The meagre remaining carbon budget required to keep global warming from exceeding 1.5°C and unleashing climate impacts with disastrous consequences for our socioeconomic systems requires a complete overhaul of the power system in the next few years. Having the appropriate organisational structures in place is a must for any chance of success.

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