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POWER SYSTEM organisational structures for the RENEWABLE ENERGY ERA

International Renewable Energy Agency

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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

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1 Introduction

The world is experiencing an energy transition that is changing how electricity is produced, transported and consumed.[1] To ensure that the energy transition is deep enough and fast enough, power system structures[2] must be recast so that they foster maximum and optimal use of renewable energy sources and technologies. Merely adjusting them will not suffice to support the transition. A paradigm shift involving the re-design of power system structures, making them fit for a renewable- based energy system, is needed.

The International Renewable Energy Agency (IRENA) began to assess the transition' simplications for electricity markets in 2014 (IRENA, 2014). It dove deeper into the topic in a 2017 study about adapting market design to high shares of variable renewable energy (IRENA, 2017a). The agency continues to provide insights on the implications of the energy transition for power system structures.[3]

This brief outlines the steps that must be taken to align power system structures with renewable based energy systems. It also explores the origins of the misalignments between the power system structure and the energy system that the transition is aiming for, providing a vision of the new paradigm requirements and discussing the characteristics of innovative power system structure designs fit for a renewable-based energy system.

Power system structure

For the purposes of this brief, **"power system structure"** is used as a short form for **"power system organisational structure"**, encompassing both the market mechanisms behind liberalised power systems and the organisational structures of regulated power systems. The term "power market" is equivalent to "power system structure" for a liberalised power system. However, because this brief broadly addresses both the liberalised and non-liberalised contexts, the term "power system structure" is used throughout.

[1] *The energy transition is driven by the need to mitigate climate change, with the energy sector contributing over 70% of overall greenhouse gas emissions (https://www.c2es.org/content/international-emissions/; https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data). Current emission trends would lead to a global warming of 4–5ºC by 2100 (https://climateactiontracker.org/global/temperatures/). The imperious need to avoid these levels of climate warming because of the strong impacts it would have on the environmental and socio-economic systems have since long been understood (World Bank, 2012). Yet a wide gap remains between the emission levels associated to current policies and pledges and the ones required to stabilise the climate at warming levels that are considered safe (UNEP, 2018). The degree of required emissions reduction and the narrow window in which global warming can be limited to the international goal articulated in the 2015 Paris Agreement on climate change make a deep, structural and fast transformation of the energy system an urgent necessity (IPCC, 2018).The urgency and depth of the required transition becomes obvious when the current proximity to Earth system tipping points is acknowledged, and the uttermost need to prevent an evolution toward a hothouse Earth climate is understood (Steffen et al., 2018).*

[2] *Bolded terms are explained in the Glossary.*

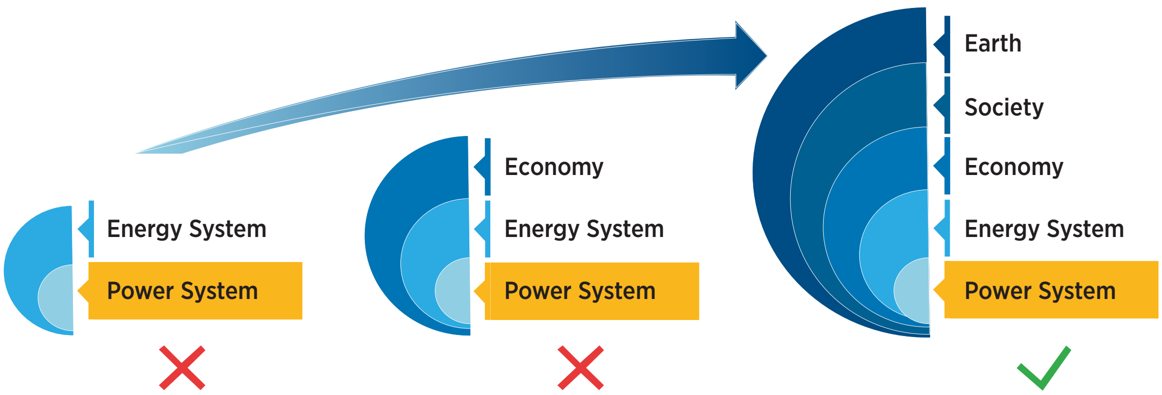
[3] *IRENA's socio-economic footprint analysis adopts this systemwide approach (IRENA, 2016, 2018a, 2019a). IRENA organised a session on market design for an integrated renewable-energy-based energy system during the 2018 IRENA's Innovation Week. Panellists (Donna Peng, Cajeme Villarreal, David Nelson, Christopher Martell and Xavier Garcia-Casals) addressed some of the most important misalignments between current power system structures and the energy transition. The presentations can be found online: https://innovationweek.irena.org/#2. In a recent report on innovation for a renewable-powered future (IRENA, 2019b) and in several related briefs (IRENA, 2019c, 2019d, 2019e, 2019f, 2019g, 2019h, 2019i, 2019j, 2019k, 2019l), IRENA's earlier work on market design (IRENA, 2017a) has been re-edited as specific innovations to complement the other two innovation dimensions (enabling technologies and business models) from the systemic approach to innovation addressed in IRENA (2019b).*

The focus is on the structures needed to organise, plan and operate the power system. Transition analyses, planning and policy making, however, require a larger picture, whereby the power system is embedded into the energy system, the economy, the society and the Earth, with multiple interactions and feedbacks between these systems **(Figure 1)** (IRENA, 2018a, 2019a).

Constrained organisational structures or allocation mechanisms (like markets) could therefore miss systemic interactions and feedbacks and hence need to be complemented with a wider systemic approach. One example is capturing the full social value of renewable energy generation beyond the power system.[4] Hence, although free market approaches may under certain conditions be more efficient in terms of economic optimisation of the power system in isolation (Munoz et al., 2017), regulated approaches might better address overall systemic requirements and thus maximise social value.

The appropriate mixture of market and regulation should therefore be pursued in each socioeconomic context, with the aim of maximising social value.

Figure 1. The embedded nature of power system structures: The transition of power systems does not occur in isolation



The power system is embedded within the energy system, which in turn is embedded within the economy, society and the Earth. Multiple interactions and feedbacks between these systems require an integrated, holistic approach to the energy transition.

[4] *IRENA's socio-economic footprint analysis adopts this system-wide approach (IRENA, 2016, 2018a, 2019a).*

Power system structures

Power system structures need to suit the characteristics of the power system they are meant to support. Power system structures, either in the form of liberalised markets[5], centrally regulated systems or a hybrid of the two, provide the framework for a power system to operate and fulfil its goal of supplying electricity to end users[7]. This is mainly framed under an economic efficiency focus (limited to the power system) where resources are allocated through market rules and prices, regulated costs and structures, or a mixture of both (Roques, Perekhodtsev and Hirth, 2016).

The power system structures currently in place, both in market and regulated contexts, were developed for the power sector paradigm of the fossil fuel era. Their objectives were to minimise generation costs while maintaining reliability and energy security. They were configured around centralised generation technologies (low cost, inflexible "base load" and higher cost, flexible "peak load") and to meet a largely passive demand.

In some instances, the goal has been the minimisation of generation and transmission costs jointly, although the mechanisms to ensure co-ordination between generation and transmission did not always reach the desired outcome. In most cases, the cost function did not include externalities (such as environmental damage), and the need for internalising these external costs is precisely what is driving the current energy transition.

The energy transition entails the large-scale deployment of renewable power generation and a change of the power consumption patterns. These transformations disrupt the current power system structures, which were not conceived to deal with the cost structure of these generation technologies (dominated by high capital costs and very low operating costs[9]), with the deployment of distributed energy resources (DERs) or with the active and dynamic participation of demand in the operation of the power system. The additional flexibility requirements[10] of variable renewable energy (VRE) pose an additional incompatibility between current power system structures and emerging generation technologies (Pierpont et al., 2017). Current power system structures are facing challenges to adequately support and efficiently structure the interactions between different components of the new system, such as renewable energy plants, storage plants, demand-side resources and increased sector coupling.

Since this is a fundamentally technologically driven challenge, both liberalised and regulated systems will be confronting it **(Figure 2)**. The intensive **capital expenditure (CAPEX)** nature and limited dispatchability of renewable energy does not fit in a system where marginal costs drive the dispatch of electricity and are the main means to recover investment. The presence of VRE calls **for increased system flexibility**, which requires a proper remuneration mechanism for resources and operators.

[5] The review of historic power sector market reforms confirms that "one size does not fit all" (Foster and Rana, 2020; Vagliasindi and Besant-Jones, 2013). Hence, this brief addresses all the different power system structure configurations associated with different mixes of liberalised and regulated elements.

[6] Hybrid power markets are the norm in most of Africa, for example, where despite reforms being prescribed and embarked on, competitive power markets have not been established. Rather, the result has been the emergence of hybrid markets where state-owned generators and independent power producers operate devoid of competition (Malgas and Eberhard, 2011).

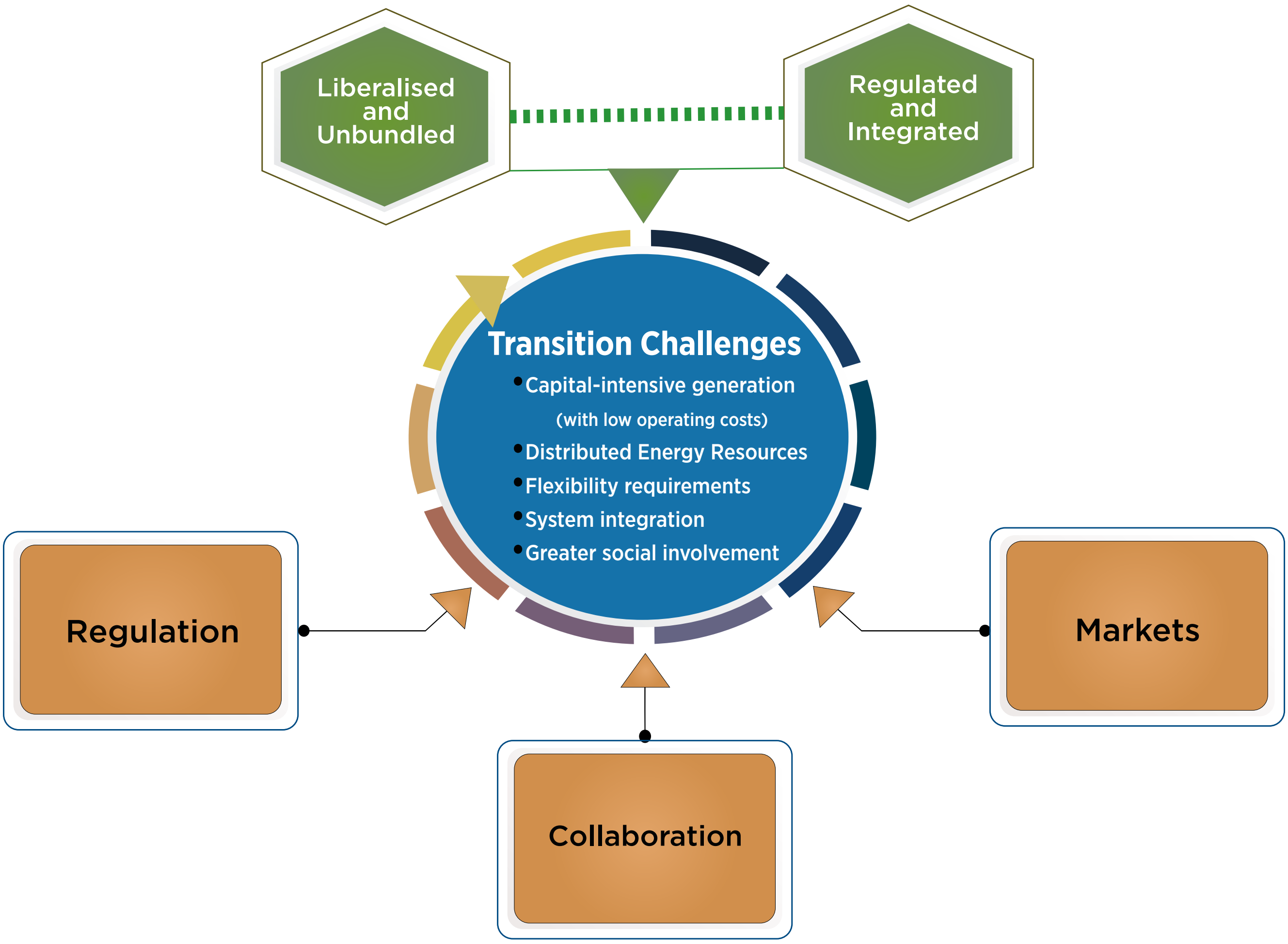
[7] How this electricity is supplied should be an integral part of the power system's goal: reliability, affordability and environmental sustainability should therefore be included in the goal's scope. However, often this has not been the case, and the electricity supply has come hand in hand with the externalities associated to missing these attributes.

[8]This brief, while referring to the fossil fuel era in broad terms, aims at addressing the transition challenges faced in one way or another by most current power systems: from capacity-constrained systems based on fossil fuel generation to energy-constrained systems designed around hydro generation. Indeed, energy constraints and climate-intensified interannual variations in hydroelectric output are triggering a growing dependence on fossil fuels in hydro-based power systems (e.g., Colombia). Hydro-based systems are also seeing an increase in capacity constraints due to the reduction of hydro storage capacity in relative terms to the size of the system and the increasing penetration of variable renewable energy (VRE) (e.g., Brazil). In the past, additional regulation beyond current power system structures was also used to support the deployment of high CAPEX/low OPEX technologies like nuclear and large hydroelectric plants (with their associated reservoirs).

[9] In the past, additional regulation beyond current power system structures was also used to support the deployment of high CAPEX/low OPEX technologies like nuclear and large hydroelectric plants (with their associated reservoirs).

[10]See IRENA (2018b) for the most recent work of IRENA on power system flexibility for the transition.

Figure 2. Transition challenges common to all power system structures



Because they are entwined with technological and social questions, energy transition challenges are found in every power system structure

The transition will entail more active actors and less passive consumption of energy. Collaboration between actors, proactive regulation and new market rules are needed to make power system structures fit for a renewable-based energy system. The right mix of collaboration, regulation and markets will depend on the specific context, but all three components can be expected to play a relevant role in re-designing power system structures (Figure 2).

How generators of electricity and providers of flexibility services are rewarded conveys crucial information in both the short term ("Should we provide this service now?") and the long term ("Should we invest in this system and commission a new unit?"). The failure of power system structures to deal with this and other transition requirements saddles users with additional costs and inhibits vital new investments, often because of inefficient regulatory adjustments.

Achieving successful system transformation will require many stakeholders to co-operate and make crucial decisions about power system structure rules, investment in generation, grid infrastructure and flexible resources. Consequently, the conceptual framework adopted for the power system structure is of critical importance. The next section lists some of the current misalignments in power system structures, followed by a discussion about a power system structure that could contribute to overcome them.

The Misalignments

Advancing the transition under current power system structures has required implementing support mechanisms for renewable energy generation. These were designed at a time when renewable power was not cost competitive against fossil fuels and represented a small share of the power system. They were created without properly accounting for the interactions between them and the power system structure. The incompatibility between renewable energy support policies and power system structures becomes more evident as the transition progresses, ultimately producing transition barriers and misalignments, leading to unintentional inefficient outcomes and regulatory fixes attempting to address those outcomes (Peng, 2018; Corneli, 2018; Blazquez et al., 2018; Newbery et al., 2017; NREL, 2015; Joskow, 2019; IEA, 2019, 2018a, 2016a, 2016b). The next sections discuss some of today's prevalent structural misalignments and several of their inopportune effects. Misalignments addressed include wholesale market pricing, valuing electricity, and retail tariffs and distributed generation. This is followed by a discussion of a proposed power system structure to overcome them.

Wholesale market

The current structures to price wholesale electricity do not work for a renewable-based power system. In liberalised systems power generation is remunerated [11] in the wholesale market [12] based on clearing prices associated to the marginal cost (composed by the operational expenditure [OPEX] and opportunity cost) of the most expensive active generator in a certain time slot[13] **(Figure 3, left)**.

Cost recovery of the investments in generation plants is mainly achieved through the cumulative differential between the plants' marginal cost and the market clearing price at each time slot, although additional remuneration can be earned through participation in other markets or remuneration mechanisms for other services needed by the power system (i.e., ancillary services). Under this power system structure, peaking power plants that operate a few hours a year rely on high market clearing prices in times of scarcity.[14]

Most renewable energy technologies have very low OPEX, making the current marginal-cost-based wholesale market structure inappropriate for a power system based on renewable energy technologies. During the transition, current regulations designed to support deployment of renewables (feed-in tariffs [FiTs], auctioned power purchase agreements [PPAs], production tax credits, renewable energy certificates, etc.) can lower the opportunity costs of renewable generation, to the point that these plants can even bid negative in a marginal cost wholesale market. This is because the whole or a big part of the remuneration from these plants does not come from the wholesale market itself, and some of their

[11] Bilateral contracts as risk-hedging instruments are also used in liberalised markets, but their pricing is, nonetheless, largely based on expectations of the wholesale market spot prices.

[12] Although we focus the discussion here on the wholesale market, a similar approach is followed in some regulated systems, since the regulator also aims at maximising the economic efficiency of the power system. However, in liberalised systems the marginal costs are provided by the market participants through their bids, while in a regulated system they must be estimated by the regulator. Cost-based electricity markets (Munoz et al., 2017) are in between liberalised markets and fully regulated systems, with deregulated investments but dispatch and pricing being conducted by the regulator based on audited costs from private generation firms.

[13] The marginal costs and generation capacity of the different plants participating in the dispatch at each time slot are ranked in ascending order (merit order), with the price being determined by the most expensive generation unit needed to supply the demand.

[14] The deployment of renewable energy in the current power system structures has increased the reliance of some thermal power plants on scarcity pricing for recovering investment costs, because of the reduction of regular wholesale market revenues (see discussion below). However, scarcity pricing is often capped in wholesale markets for socio-political acceptance and to prevent the exercise of market power. This is one of the reasons for the introduction in several markets of additional regulated payments known as capacity remuneration mechanisms (CRMs), which besides arguably being less efficient for resource allocation than proper price formation (scarcity pricing) (Hogan, 2017) have also raised concerns about further market distortions, delaying the transition and increasing fossil fuel subsidies when these need to be phased out. For present purposes, basing investment cost recovery on unconstrained scarcity pricing does require dispatchability, and hence it is not an option for most renewable energy generation technologies in a renewable-energy-based power system. Efficiently separating the different requirements of electricity and flexibility procurement in a renewable-energy-based power system is what leads to the dual market proposal discussed below.

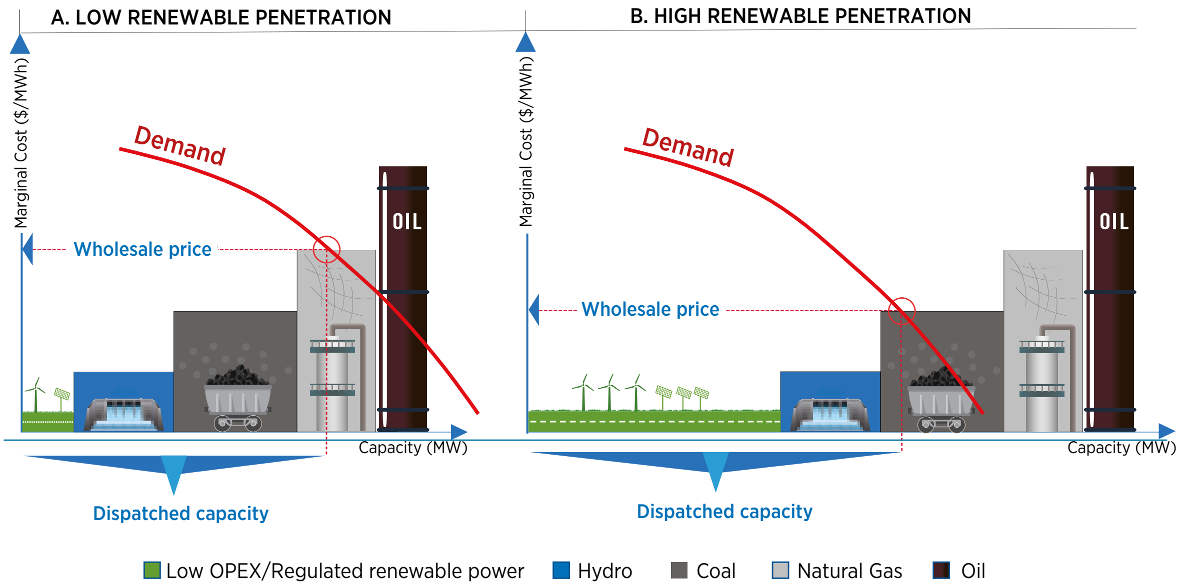
income (production tax credits, renewable energy certificates) depends on dispatching electricity whatever its wholesale price.

Low marginal cost renewable energy generators displace conventional thermal generators with higher marginal costs, thus reducing the volume of electricity sold by these higher marginal cost generators **(Figure 3).** Moreover, due to the wholesale market structure and the low marginal costs of renewable energy or its regulated remuneration and priority of dispatch, increased renewable energy generation decreases the wholesale market prices causing conventional thermal generators to suffer from reduced electricity prices. A reduction in sales and electricity prices leads to a reduction in annual income for conventional thermal generators, jeopardising their capability to recover costs through this market mechanism.[15] This merit order effect is magnified in the case VRE resource availability coincidences with low demand.

The first generators to suffer in this situation are typically[16] gas-fired power plants (e.g., combined cycle gas turbines, CCGTs), which provide the current bulk of the system flexibility in many systems and already operate fewer hours than inflexible baseload plants (e.g., coal, nuclear power plants).

Fossil fuel generators will be gradually decommissioned as the power system is transformed to address climate constraints[17] (IRENA, 2018a).

Figure 3. Evolution of wholesale market price and dispatched capacity: Low vs high shares of low-OPEX/ regulated renewable power generation



Note: Each block represents a generation technology, shown in ascending order of marginal cost (merit order).
MW = megawatt; MWh = megawatt hour; OPEX = operational expenditure.

In wholesale power markets, the price of electricity in a specific time slot is set at the intersection of the demand curve (red line) and the supply curve. The presence of large shares of low-OPEX/ regulated renewable generators depresses prices and reduces the energy volumes sold by generators with higher marginal costs

[15] *This, together with the caps in scarcity pricing, is referred to as the "missing money" problem (i.e., the revenues in the energy market will not cover the needed investments in new capacity, thereby failing to ensure the long-term adequacy of the system), which drives the requests for additional regulation (i.e., CRM) that allows conventional generators to recover investments.*

[16] *Although in general terms it depends on what is the dispatched technology with the highest marginal costs, which in turn is linked to domestic fuel costs and availability, and to the existing generator fleet.*

[17] *The need to limit global warming as much as possible, aiming at below 1.50C as per the Paris Agreement.*

However, retirement of the most flexible fossil fuel generators must not outpace the deployment of other sources of flexibility fit for a renewable-based energy system, since flexibility and reliability must be assured at all times. On the other hand, the retention of conventional flexible fossil fuel generators should not be permitted to block or delay the deployment of the needed new forms of flexibility (Liebreich, 2017). Power system structures will have to be modified to keep these two imperatives in balance.

In systems where renewable power has already affected conventional thermal generators' business cases, **capacity remuneration mechanisms (CRMs)** have been implemented or discussed as an adjustment to the current power system structures (van der Burg and Whitley, 2016). CRMs allow the recovery of fixed costs for power plants that are unable to recover them in the wholesale market due to infrequent use and low market clearing prices. However, if not properly structured, CRMs may prolong the life of ultimately unnecessary power plants through additional fossil fuel subsidies and slow the procurement of renewable power generation and new sources of flexibility that are fully compatible with the use of renewables, ultimately delaying the energy transition and raising its cost.

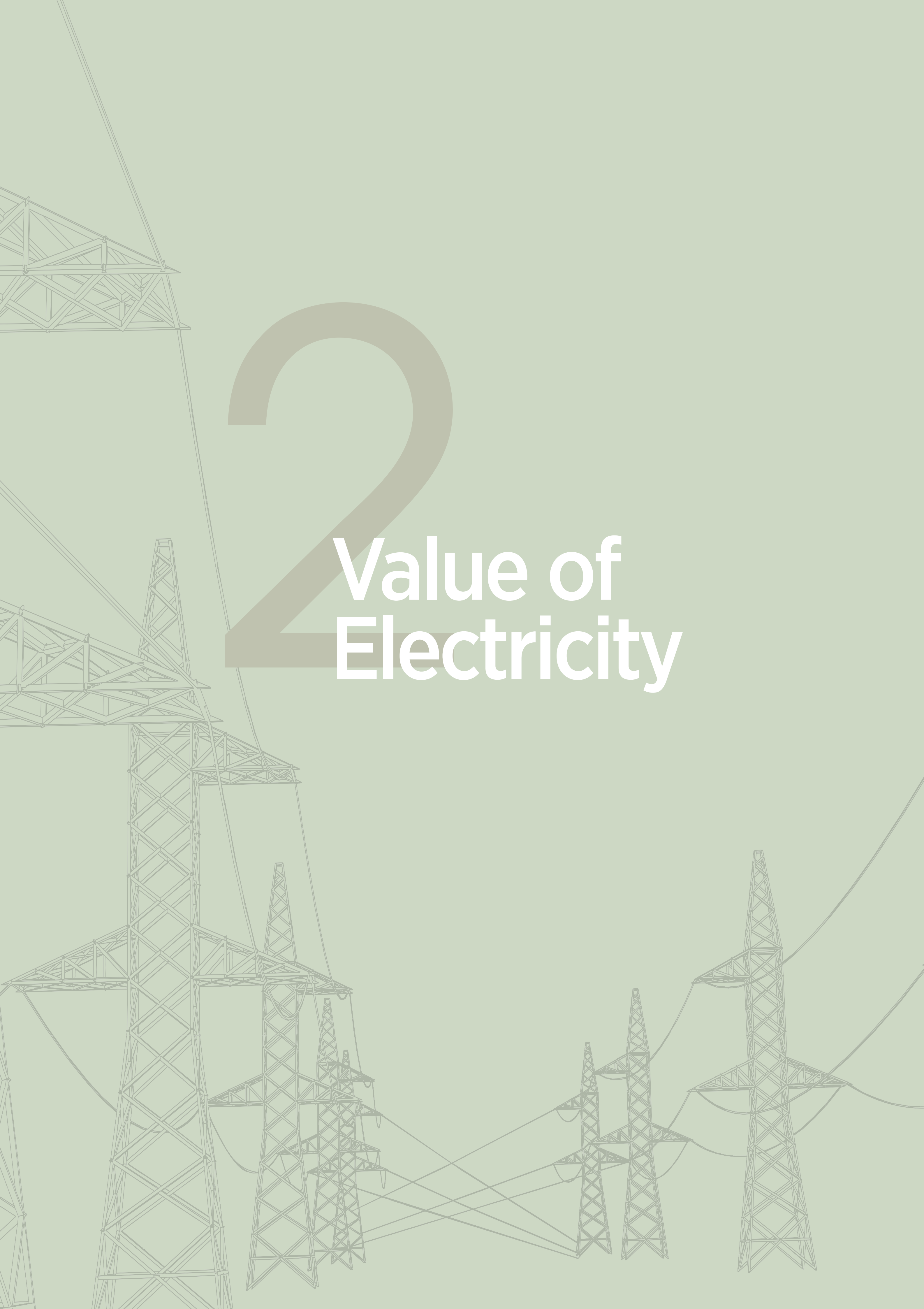
Deployment policies such as feed-in schemes and auctioned PPAs have allowed renewable power technologies to become mainstream even while deriving little income from participation in the wholesale market.

These non-market payments play a double role: On the one hand, they encourage renewable power generation (based on social value), pushing the technologies ahead on the learning curve and into growing prominence in the power system. On the other hand, they are a regulatory fix that allow renewable power technologies to be deployed within power system structures that ultimately are unfit for them. [18, 19] Hence these payments are very different in nature to the subsidies provided to established technologies (i.e., fossil fuels) without renewable energy's social value.

Even when renewable energy technologies could reach a lower **levelised cost of electricity (LCOE)** than fossil fuel technologies, the current power system structures would not be able to support their large-scale deployment while benefiting from renewable energy's potential low LCOEs. This is because finance risk premiums would artificially inflate renewable energy's LCOEs and depressed electricity prices would discourage additional investments. In summary, as renewable power deployment gains traction, current wholesale pricing mechanisms become increasingly unfit both for conventional generation technologies and for renewables. Beyond the perturbations that this introduces for fossil fuel generation plants, the fundamental issue with this misalignment is the inability to support a renewable-based power system (Newbery et al., 2017).

[18] FiTs and PPAs enable this regulatory fix by providing a stable and predictable revenue stream aligned with the LCOE of investmentdominated technologies, rather than the revenue stream from significantly lower and more volatile market-clearing wholesale prices based on marginal costs (further depressed by the deployment of renewable energy into the power system). The prospect of stable, predictable revenues reduces investment risk and thus the cost of capital, thereby lowering the LCOE derived from renewable energy technologies. This is why the conceptual framework of FiTs and PPAs seems fit for a renewable-energy-based power system, and hence constitutes one of the two pillars of the approach discussed below.

[19] VRE generators are the most sensitive to depressed spot prices, since they can operate only when the resources are available, and hence are quickly affected by this misalignment. Although technology options exist to shape renewable power production curves in a more system friendly way (IEA, 2016b), they do not cure the fundamental misalignment.



2 Value of Electricity

The cost, price and value dimensions of electricity are often misaligned. Insights into the origins of these misalignments can contribute to the power system structure better capturing the value of electricity. One of the main goals of policy makers charged with designing direct incentives for renewable power technologies is to produce the most power at the least public expense (price minimisation).[20] This is the main driver behind the use of auctions (IRENA/CEM, 2015; IRENA, 2017b, 2019m).

While this is commendable, it may not be sufficient to eliminate misalignments between costs, prices and value.[21] For instance, the more low-OPEX renewable energy is produced, the more clearly 1 megawatt hour (MWh) does not have the same power system value for every location and every point in time. Notably, the social value of renewable-based generation beyond the power system is not captured by price minimisation approaches limited in scope to the power system. The power system structure should aim at aligning the value and price of the produced electricity within the power system,[22] while providing mechanisms for appropriate cost recovery. This section presents a discussion of the power system misalignments in the cost, price and value dimensions. The concepts included under these dimensions are explained in **Box 1**.

Time and location are important components of the value of electricity. As production of renewable power grows, the value within the power system of a unit of generated electricity comes to vary more widely by location and over time.

Additional regulated payments such as FiTs and PPAs, when irrespective of the location and timing of energy production, implicitly push developers to find a location where resources are abundant and to adopt plant designs that minimise costs and maximise generation. This drives down the market price of energy, increasing the need for additional regulated payments, while simultaneously leading to higher grid investment requirements (e.g., reinforcement of grids to connect resource-rich areas with load centres), and the need to procure additional flexibility resources.

[20] However, public expenses to integrate this renewable energy generation in the energy system can go beyond auction prices when these do not reflect all cost components (IRENA, 2019m).

[21] Basic auction mechanisms can be upgraded and fine-tuned to address some of these misalignments (IRENA, 2019m).

[22] For adequate allocation, the social value beyond the power system should in principle be rewarded through socialised price complements, and not through the power system price. However, when costs are higher than power system prices, and in the absence of appropriate socialised price complements, rewarding the value beyond the power system through power system regulated payments or subsidies could be instrumental in achieving the socially beneficial diffusion of this technology into the power system.

Box 1. The cost, price and value dimensions of the generation of electricity

Cost

The cost dimension includes two components: the levelised cost of electricity (LCOE) and the (negative) externalities. Costs consist of internalised costs and externalised costs:

- **Internalised costs** are the monetary costs faced by the owner of the generation plant; in annualised terms these are represented by the LCOE and include debt and equity servicing costs.
- **Externalised costs** are those costs not covered by the owner of the plant – in other words, society pays them. An externalised cost can be internalised – for example, by introducing a Pigouvian (or corrective) tax equal to the external cost, in which case it becomes incorporated into the LCOE. This is the case with carbon taxation for internalising climate damages. The absence of a proper internalisation of all costs constitutes a distortion of power structure allocation mechanisms (be they market or regulated), thus hindering the optimal allocation of resources. The internalisation of externalities would significantly increase the competitiveness of renewable power generation.

Price

The price dimension includes three components – market prices, additional regulated payments, and subsidies:

Prices are the financial reward for providing a product or service. Prices can be set by a market mechanism, by government fiat or by regulation. In this report, price includes two distinct elements: the **"market price"**, which is shorthand for the price generated directly by the power system's structure, and **"price complements"**, such as subsidies and additional regulated payments.

Subsidies are additional payments (price complements) made to support a given power generation technology. Several differentiations come into play including:

- **Direct vs. indirect subsidies**. Direct subsidies include all the various production and consumption subsidies to fossil fuels. Indirect subsidies consist of the price paid by society for the external costs of the technology, which in the case of fossil fuels dominate the total amount of subsidies (IMF, 2015). Indirect subsidies are the difference between post-tax and pre-tax subsidies as per IMF (2015).
- **Subsidies that reward social value vs. those that do not**. For instance, subsidies to renewable power generation can be linked to the additional social value that it provides, while subsidies to fossil fuels cannot.
- **Subsidies that play a role in spreading new technologies** within the power system and those that no longer play this role because the technologies are already established. In the case of a renewable power technology that still needs to advance along its learning curve, subsidies can facilitate this process, thereby contributing to the diffusion of its social value.

Value

Value is how much something is worth having. The value dimension includes two components – power system value and additional social value:

- **The power system value is associated to the location and time of generation**, since a unit of generation is worth less if produced in a location affected by transmission or distribution congestion or if produced in a moment when demand is low and overall generation high. Power system value has implications for investment and for operational requirements (building new lines, reinforcing transformers, procuring additional flexibility, etc.).
- **The additional social value captures the value of the generated electricity for society** beyond the power system. It includes elements such as climate change mitigation, the provision of adequate jobs, the coverage of basic needs and the enabling of economic activity. Power system resilience contributes to both the power system value and social value. Hence, social value goes beyond the mitigation of greenhouse gas emissions or pollution and can differ from one renewable power technology to another, and even for a given technology deployed in different contexts.

There may be several reasons why one plant may have a higher social value than another. For example, it produces more or better jobs, activates the economy in a depressed area, allows part of its benefits to flow back to the community, makes less or more sustainable use of scarce materials, or sources its material and human input through fair trade and relationships. The effective contribution of the energy transition to the democratisation of the energy system can also have significant effects on the social value of the produced electricity (Burke and Stephens, 2018).

This brief does not attempt to propose a specific methodology to quantify the value of generated electricity, but rather to provide a conceptual framework within which to consider the value dimension. Attempts are being made to incorporate power system value into policy making, energy planning and energy procurement through for example, value-based auctions (Villareal, 2018; IRENA, 2019m). Investigators are assessing aspects such as the time and space value of generation, and its integration, flexibility, capacity and resiliency values for the power system (Jorgenson et al., 2013; Denholm et al., 2015; Milligan et al., 2017; IEA, 2018b; Anderson et al., 2018).

The value-adjusted LCOE introduced in IEA (2018b) combines into a single indicator the LCOE and a proxy of the energy, capacity and flexibility value of the produced electricity, although the indicator does not succeed in capturing all the costs and benefits related to each technology (for example, network integration costs and non-priced environmental externalities are not captured). The conceptual approach followed in this brief differs from that used in IEA (2018b): Instead of lumping cost and value elements into a single parameter that represents neither cost nor value, this brief retains the conceptual differentiation between the cost and value dimensions with the aim of properly informing the discussion.

Box 2. Mexico's value-based auctions

Mexico has introduced an ambitious power sector reform, liberalising a monopoly system while integrating new clean energy procurement mechanisms (Villareal, 2018). The cornerstone of the reform is the auction system for energy, capacity and clean energy certificates, which is one of the most sophisticated procurement mechanisms in place.

Auctions are held by the Centro Nacional de Control de Energía (CENACE) at least once a year. In this auction system, location-specific and time-dependent adjustment factors during the bidding process are used to favour project development in specific regions and with specific time generation profiles. Hourly time- and location-dependent energy price adjustment factors for variable renewable energy are set by CENACE through long-term energy models. The adjustment factors are added to the winning bids' prices, providing long-term signals of the needs of the system. In hours where the adjustment factors are positive, the VRE producers receive the bid price plus the adjustment factors. Similarly, when the adjustment factor is negative, this amount is deducted from the bid price. These adjustment factors are clearly presented during the auction launch, so that developers can build their business cases around them.

In three auctions, from 2015 to 2017, the average winning bids' price decreased from USD 47.8 to USD 20.6 per megawatt hour.* Wind and solar photovoltaic were the main beneficiaries, with a small share of geothermal in the second auction. In three years, almost USD 9 billion was invested in clean technologies. The winning plants were situated in areas where their generation can provide more value. For example, the northwest, where energy costs more in summer due to high temperatures, saw an influx of new solar photovoltaic plants. Meanwhile, winning bids of wind farms were located in areas where energy is valuable owing to the lack of gas pipelines, grid characteristics and the presence of tourism activities (Villareal, 2018).

The Mexican auction design aims to find a balance between the need for long-term revenue certainty and the competitive procurement of technologies that have higher value for the system. This ex ante approach to energy value needs to address the challenge of the dynamic nature of the power system transformation, which will produce a time-dependent evolution of the locational and time value of electricity generation.

*Note: These low bidding prices could also be a cause of concern since underbidding can lead to underbuilding (Hochberg and Poudineh, 2018).

Often renewable energy plants enjoy priority of connection and connection charges that do not capture the full connection costs, even when the grid needs to be reinforced or created ad hoc for these new plants.[23] Grid costs are mainly passed on to end-users. The lack of appropriate time and location pricing signals and the associated disconnect between generation and grid costs can lead to higher overall costs for society and the final user, as well as to the risk of grid congestion and curtailment of VRE generation (Peng, 2018; Liebreich, 2017). Some policies already recognise the time and locational value of renewable power, for example, introducing time-dependent tariffs and locational price signals to minimise the aggregate of grid and energy costs. Mexico's value-based policy design serves as an interesting example **(Box 2)**.

As the energy transition progresses, time and locational signals for flexibility will also gain importance, to assure the investment in resources able to provide flexibility where and when this is most needed.

[23] Not capturing the full connection costs in the connection charges, and specifically the requirements for grid reinforcement, has also happened in the past and is still happening today with fossil fuel or nuclear plants.

If a technology needs additional support because of the market price[24] not covering its costs, this can be accomplished through an additional regulated payment or a subsidy that covers the difference between the market price and the technology cost. But this should always be conditional on the social value from this technology. Subsidies to technologies without social value should be phased out (i.e., fossil fuel subsidies), and in any case hidden subsidies[25] (implicitly paid by society but not explicitly recognised) covering external costs should be eliminated.

An important difference between an additional regulated payment and a subsidy is often overlooked. A subsidy is an additional payment (a price complement) made to achieve the political aim of supporting a given technology. And the possible motives are many. They include the desirability of spreading the technology within the power system (as is the case with renewable energy), supporting the localisation or competitiveness of given industries, safeguarding jobs, and responding to lobbying pressure, among others. An additional regulated payment, on the other hand, attempts to correct an identified flaw in the implemented pricing structure.

FiTs and PPAs, like CRMs, can be understood as additional regulated payments to overcome the unsuitability of the current power system structures to accommodate renewable-based power systems, although FiTs and PPAs may include elements of subsidy as well as additional regulated payments while the technology they support is still advancing along its learning curve. Rewarding the additional social value provided by electricity generation may be another goal of additional regulated payments. The term "subsidies" effectively lumps together fundamentally different elements.

Pricing complements provided to technologies harmful for society (e.g., fossil fuel subsidies) are not the same as pricing complements provided to renewable power so as to address the unsuitability of the power system's pricing mechanisms. Describing them with the same, homogenous label is often misleading and may be conceptually wrong. This becomes evident when proposals for power system structure reform like the approach discussed below take the conceptual framework of the current FiT or PPA to become one of the pillars from a market structure fit for renewable-energy-based power systems.

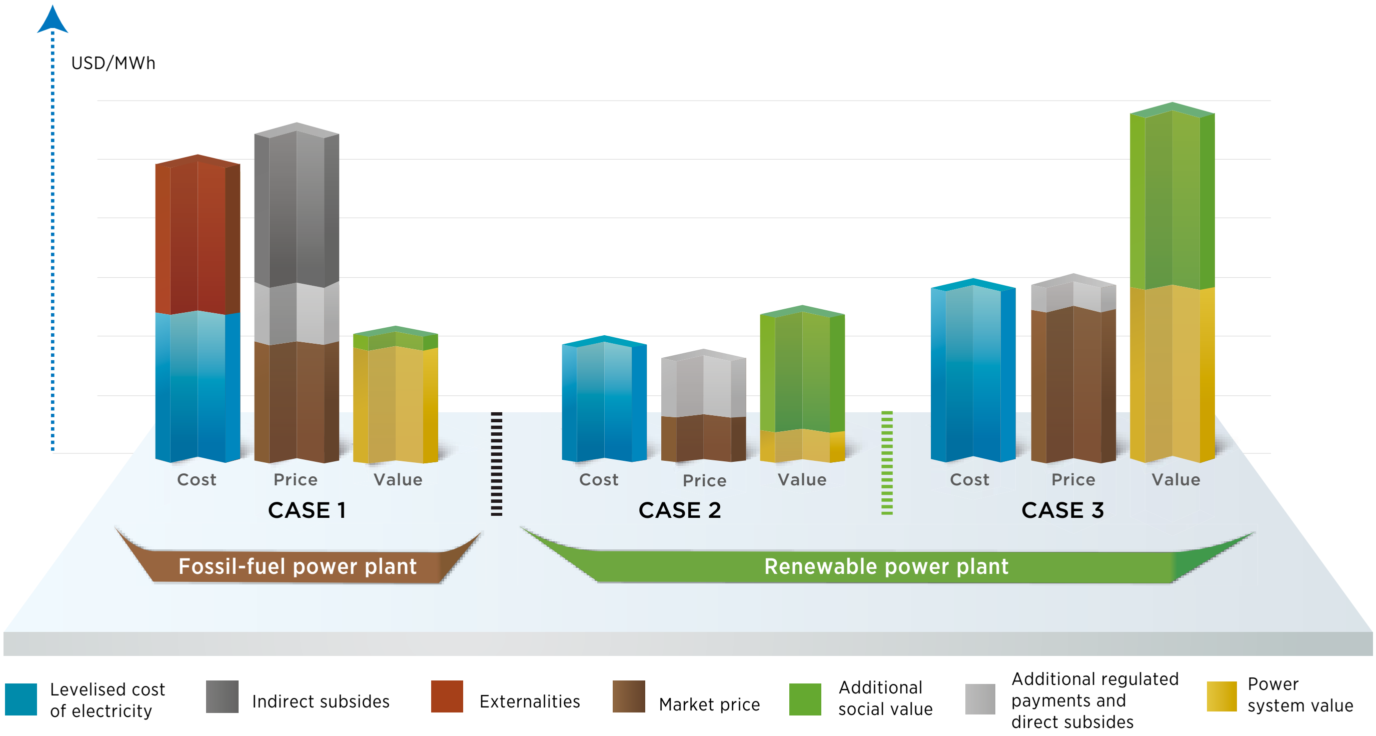
The mismatches among costs, prices and value for renewable-based and fossil fuel generation plants operating in different situations and system structures are illustrated in **Figure 4**.

[24] The term "market price" is used here to differentiate the part of the price directly allocated by the power system structure, which in the case of a liberalised system would be the market clearing price, but for a regulated system would be the regulated or stipulated price. This allows differentiating this "market price" from the overall price category that includes other regulated payments and subsidies. Hence, the "market price" should be understood as a shortcut for the "direct power system structure price".

[25] Like those addressed in IMF (2015) as post-tax subsidies (subsidies related to externalities).

The cases presented in the figure illustrate potential misalignments of cost, price and value. The point of the figure is not to establish associations among the presented cases and specific real-life situations, but rather to focus on the conceptual level using generic examples to illustrate the relevant misalignments. Many combinations of technologies, power system structures and contexts (both present and future) could fit within each of these cases. For instance, **Case 2** could mirror a current power system structure characterised by high photovoltaic (PV) penetration and bad alignment between PV generation and demand, while **Case 3** could be mirroring concentrated solar power with thermal storage or PV accompanied by battery storage in a power system structure fit for renewable power technologies. Additional details on each of the cases are provided in **Annex A**.

Figure 4. Cost, price and value of electricity (illustrative annual averages)



Note: MWh = megawatt hour.

In a well-designed power system structure, prices would be aligned with costs and overall power system value, with additional social value providing a positive social balance, and additional regulated payments/subsidies would be minimised.

For a fossil fuel power generation plant operating in any current market **(Case 1)**, additional regulated payments and subsidies can be significantly higher than for renewable power generation. This is especially true when unintentional, indirect subsidies are factored in.

Yet the same plant's overall value may be significantly lower than electricity prices and costs alone would indicate.

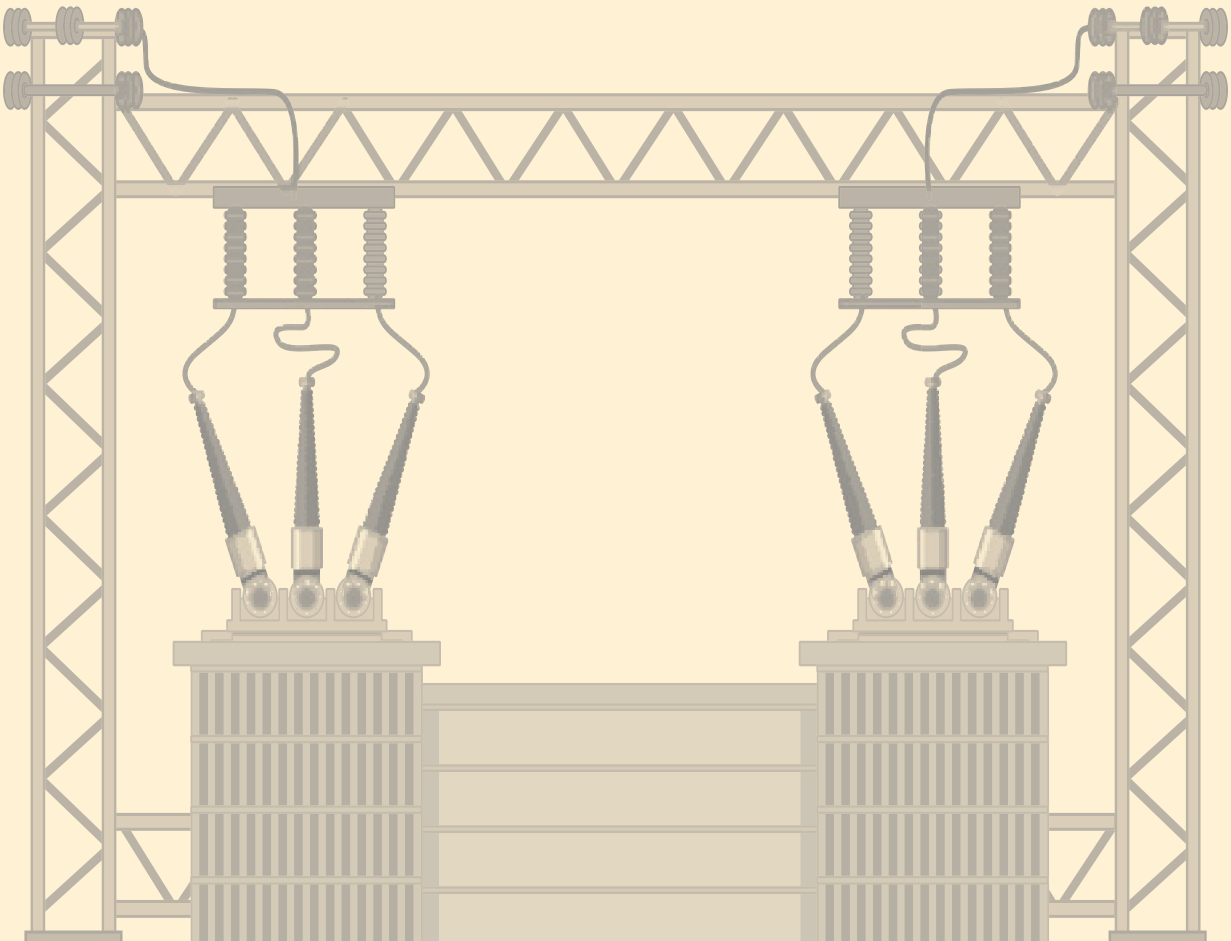
Cases 2 and 3 correspond to renewable power generation plants under the current power system structure **(Case 2)** and a power system structure fit for renewable energy technologies **(Case 3)**. **Case 2** has lower costs than **Case 3**, but the value of the power system is also lower in **Case 2**. Moreover, since the power system structure in **Case 2** is not fit for renewable power, it needs higher additional regulated payments.

CASE 1 represents a fossil fuel generation plant operating under a current power system structure. The **market price**, aligned with the **power system value**, is significantly lower than the technology's LCOE. If this generator has already recovered its investment costs (perhaps in part thanks to other subsidies received in the past), the generator can continue earning profits (even windfall profits) as long as the market price remains above its marginal costs. However, if its investment costs are not recovered or if the penetration of renewable power into the system depresses the market price below its marginal costs, **the generator will require additional regulated payments or direct subsidies (like CRMs).** [17] In **Case 1** **the sum of the market price and additional regulated payments/ direct subsidies exceeds the LCOE**, illustrating an economic inefficiency even when considering only the scope of the power sector. Moreover, since this fossil fuel technology has significant **externalities** (climate change, pollution, etc.) that are not internalised in its LCOE, there is a high **hidden indirect subsidy** – that is, a price paid by society to cover external costs. The overall value of the electricity produced in **Case 1** (the power system value plus the additional social value) is significantly lower than its price and cost, providing a negative social balance. **Case 2** represents a renewable power generation plant operating under a current power system structure with a **market price higher** than the **power system value** of the generated electricity. This renewable power technology has already reached low LCOE (even lower than for the fossil fuel generation in **Case 1**), but the market price determined by the marginal cost market, despite being higher than the power system value of the produced electricity, does not cover the generator's costs. Hence, **an additional regulated payment** must be added to the market price.

CASE 2 sees that payment falls short of what is needed to attain economic sustainability. There are **no subsidies** in **Case 2**, since the renewable power technology has already advanced along its learning curve to the point of reaching competitive LCOEs, and no externalities are associated with it. **The additional regulated payment** addresses the misalignment of the pricing mechanism from the marginal cost power system structure with the life-cycle costs of producing electricity. **When the additional social value** derived from this form of electricity generation is taken into account, its overall value is higher than the costs and price, providing a positive social balance that, if rewarded through an additional socialised price complement, would provide economic sustainability for the plant.

CASE 3 represents a renewable power generation plant operating under a power system structure designed expressly to accommodate renewable power technologies. Despite a higher LCOE than in **Case 2,** **the power system value** of the generated electricity is higher because of its location and time characteristics. The use of a power system structure appropriate for renewable power generation yields a much better alignment between **market price** and LCOE. The **small additional regulated payment** still needed in **Case 3** is due to the fact that the **market price** still does not capture **full power system value**. Improving the alignment of market pricing mechanisms with the value of the generated electricity for the power system would remove any need **for additional regulated payments**. The overall **value** of this case greatly exceeds its cost and price, providing a positive social balance which perhaps should be rewarded through an additional socialised price complement. The additional social value is higher in **Case 3** than in **Case 2**, even though both involve renewable power generation and hence provide the same climate change mitigation. This is because **Case 3** addresses other social components. This highlights the fact that not every renewable energy deployment will result in the same contribution to a sustainable and resilient energy transition. Hence, policies must consider the different components of the socio-economic dimension and pursue transition approaches that maximise overall social value.

3 Load defection and social inequalities



Another misalignment between the prevailing market structure and renewable energy support schemes lies in how the costs of such schemes are recovered. Renewable energy support costs and network charges are levied on retail consumers, mostly through energy (volumetric) charges in the retail market. When capacity (fixed) charges are introduced or increased in retail tariffs to recover a larger share of renewable energy support and grid costs, the resulting tariffs can discourage energy efficiency while also failing to reap the benefits of demand-side response.[26] Moreover, retail electricity prices are often time-insensitive, thus providing no signal for flexible consumption or "prosumption".

Rising retail prices and inflexible price structures encourage investment in self-consumption solutions like residential PV (increasingly with storage), a decision that is often reinforced by specific policy measures (e.g., net metering). The resulting influx into the grid of more distributed generators, coupled with grid digitalisation, may then necessitate additional investments in transmission and distribution infrastructure. Because operators of distribution and transmission systems recover a big part of their costs from energy bills, mostly on the basis of the volume of electricity distributed,[27] reductions in the volume of electricity consumed starve operators of potential investment funds.

The combination of falling costs of DERs and rising grid-electricity costs, together with other drivers of distributed self-generation (such as cost stability, environmental concerns, resilience, and eroded trust in utilities) opens the door to a new paradigm where utilities (directly or through retailers in liberalised markets) lose their monopoly on providing electricity and need to convince potential customers of their social value. Load defection, and eventually grid defection, if not properly addressed may lead the grid into a death spiral which, unless stopped, may deprive society of the social value of the grid.

[26] As often implemented today, high capacity charges in the retail tariff lead to small marginal monetary savings from deploying energy efficiency because of the high relative impact of the fixed charge on the final price (the less electricity is consumed, the higher the overall price per unit of the remaining electricity consumption becomes, thereby reducing the potential savings from efficiency measures). Simultaneously, high capacity charges disincentivise contracting the higher capacity that would be needed to advance electrification (an important efficiency and system integration measure) and to provide meaningful demand-side response capabilities (flexibility requirements from a renewable-based power system are mostly linked to capacity regulation).

[27] There are other transition measures, like the deployment of energy efficiency, that also lead to a reduction of the traded volume of electricity. But the focus in this section is on self-consumption from prosumer-owned distributed generation and self-consumption because the misalignment we are addressing is about renewable power support mechanisms. Moreover, this misalignment may lead to the grid death spiral due to several powerful feedback loops (e.g., their deployment potentially requiring a reconfiguration of the grid and the evolution of retail tariffs incentivising it).The deployment of energy efficiency does not present these strong feedback loops, but like prosumer-owned distributed generation and self-consumption, it also leads to a reduction of the traded volume of electricity, and hence shares with it the split incentives problem. The latter acts as a barrier for significant deployment of these technologies up to the scale needed for a meaningful transition. The split incentives misalignment is mainly linked to the structure of the business model used by utilities and could be addressed by the migration from an energy-based to an energy services-based business model.

The feedback mechanisms behind the death spiral can be checked by recognising and monetising both the value and the costs of DERs. The principle behind the death spiral is the following: more self-generation and self-consumption imply less energy generated and distributed by the central system, which, under prevailing tariff structures and grid-remuneration mechanisms, would result in a smaller basis for the recovery of the costs of the grid and of renewable power support schemes. In the process, the price of grid electricity is increased, mainly affecting users fully dependent on the grid who have not invested in DER solutions (Bronski et al., 2014, 2015; Peng and Poudineh, 2017; Peng, 2018).

Vulnerable, low-income consumers, who cannot afford the initial investment in self-consumption or energy efficiency are then burdened with disproportionate shares of grid charges, increasing social inequalities (Bouzarovski, 2018). This misalignment thus transcends the energy sector and enters the social sphere. This situation is not inevitable. With the appropriate redesign of the power system structure and retail tariffs there is another potential pathway along which the power system could evolve because of the shift in paradigm introduced by the widespread adoption of DERs, swelling user participation and marginal operating costs approaching zero (Bronski et al., 2015; Lo et al., 2019). If grid operators would pursue collaborative and inclusive fair approaches with the deployment of DERs, the evolution would be geared toward an integrated power system where both DERs and grid assets provide their value, minimising energy costs for all users.

The actual adoption of this pathway depends on the early deployment of the right market and regulatory mechanisms and a holistic approach to retail pricing redesign that considers the evolution away from current rate structures and toward a valueof- service approach (Lo et al., 2019). One example of a regulatory mechanism in this direction comes from Australia **(Box 3)**.

DERs have an important role to play in the transition, empowering end-users to have an active role in the configuration and operation of the energy system, facilitating the high involvement and participation that the transition requires, improving the governance of the power system, providing resilience and unleashing a huge potential for generation and flexibility.

Box 3. Australia's embedded networks

The two pillars of a power system structure conducive to a thorough energy transition are: renewables-based generation and the incorporation into the power system of sufficient flexibility to take full advantage of that generation. The required flexibility depends on the possibility of demand response, the availability of storage, the appropriate aggregation of distributed energy resources (DERs) and the presence of effective collaborative structures (see Figure 2). Ongoing experiences on these fronts provide the building blocks for re-designing the power system structure. The Australian experience with embedded networks (ENs) is instructive (Martell, 2018).

Australia's power system has several elements that make it unique. Residential photovoltaic (PV) is more developed and deployed than utility-scale PV, with 20% of Australian homes and businesses possessing solar PV systems; Australia also has some of the most expensive electricity in the world; in 2018-2019, coal provided the bulk of total generation (71%), but wind and solar PV have a significant share as well (14%).

Portions of the country's distribution grid that have a specific electrical wiring configuration can become ENs, enabling the owner of the site (the "EN manager") to buy energy from an energy retailer and then resell it to end-users at the site. Sites include housing estates, apartment buildings, retirement villages, educational centres, shopping centres and industrial complexes. The direct purchase of electricity is not the only benefit. As small "energy retailers", EN managers have advantages to invest in self-production, efficiency and storage solutions to reduce energy expenditures. The EN design in fact removes the barriers to property owners investing in DERs and allows owners and tenants to share the benefits of locally produced DERs. The union of the EN framework and new technologies (e.g., storage, demand-side response, solar PV, digitalisation) makes possible the creation of active interconnected, independently managed mini-grids.

The arrangement provides value not only to users, who can access clean, inexpensive energy and participate in community-owned DER systems, but also to the grid. Today, ENs can provide frequency control, voltage regulation and demand response services. With storage, EN owners can enjoy tariff arbitrage and delayed PV self-consumption. ENs can also provide solutions to grid congestion and add flexibility in the timing of grid investment.

Almost 5 000 ENs came online in the five years before 2019. The Australian example shows the potential of a retail market adjustment that enables demand-side and distributed energy resources to participate in the market and provide value, engaging consumers with simple offers and streamlining the creation of local aggregators, coupled with digitalisation and technology advancement (Martell, 2018). ENs are an active example of how DER deployment can enhance an integrated power system, contributing to cost minimisation through collaborative arrangements.

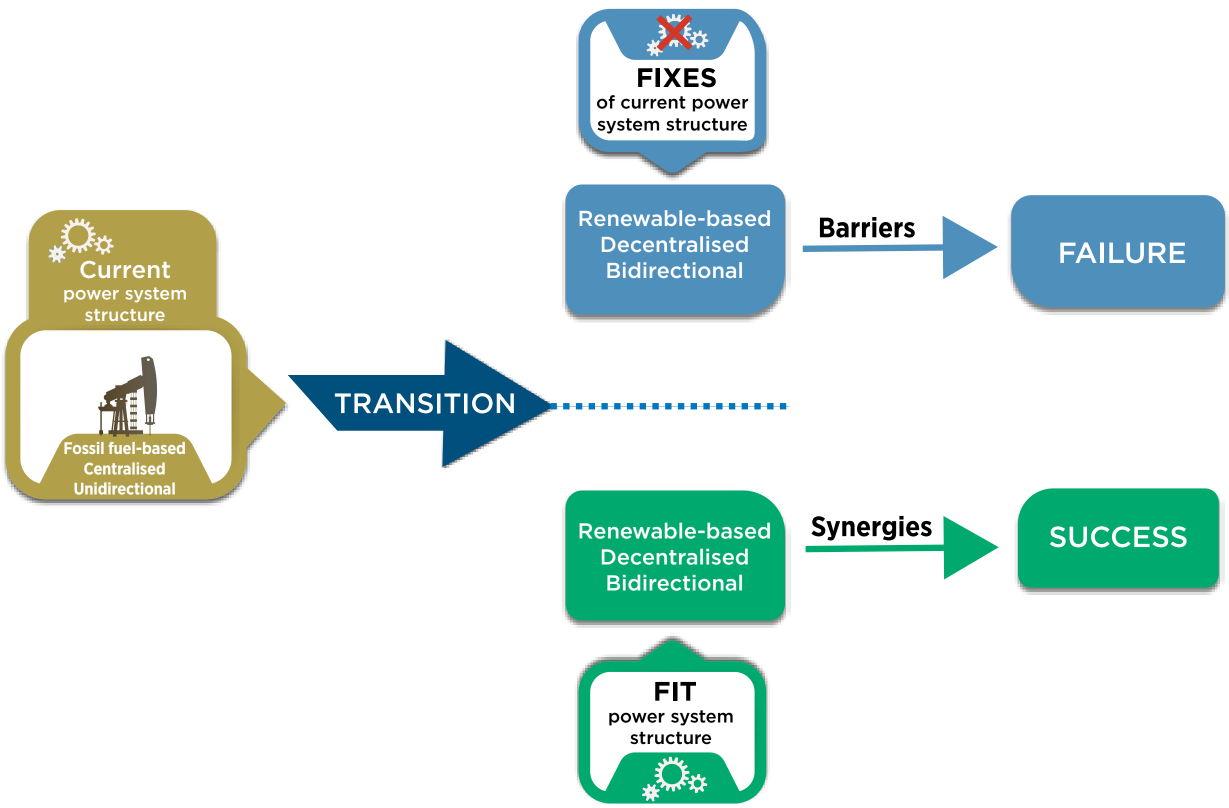
4

The way forward

The three misalignments discussed in this brief are among the main ones, but there are other inefficiencies and misalignments between renewable energy policies and current power system structures (Peng and Poudineh, 2017). There is a risk that, under a narrow vision of the overall situation, these misalignments become arguments against further renewable power deployment and are, in fact, already used in different cases as such (Agora, 2018).

This must be prevented given how much depends on the success of the on-going energy transition. The first step toward a successful transition, as presented in the previous sections, is developing a holistic vision that allows identifying the root causes of these misalignments and providing insights on how to address them. Next step is evolving toward a power system structure that addresses these misalignments. The transition requires an evolution from a fossil-fuel-based, centralised and unidirectional power system with relatively few actors toward a renewables-based, decentralised and bidirectional power system with a multitude of actors on the supply and demand sides. Until now, efforts to encourage this evolution have involved adjustments to the current power system structure, which have produced the misalignments analysed above. Without a more comprehensive rethinking of the power system structure, those misalignments will create barriers that could delay or even defeat the energy transition **(Figure 5)**. The time has come for a new power system structure that can support the energy transition and the power systems of the future.

Figure 5. Impact on the energy transition of how the required power system structure updates are addressed (fixes versus re-design to be fit)



The power system structure must be re-designed in order to suit the new energy system where the transition is heading to. Merely introducing fixes to the current power system structure would create a dysfunctional configuration with misalignments producing barriers that hinder the ultimate success of the energy transition

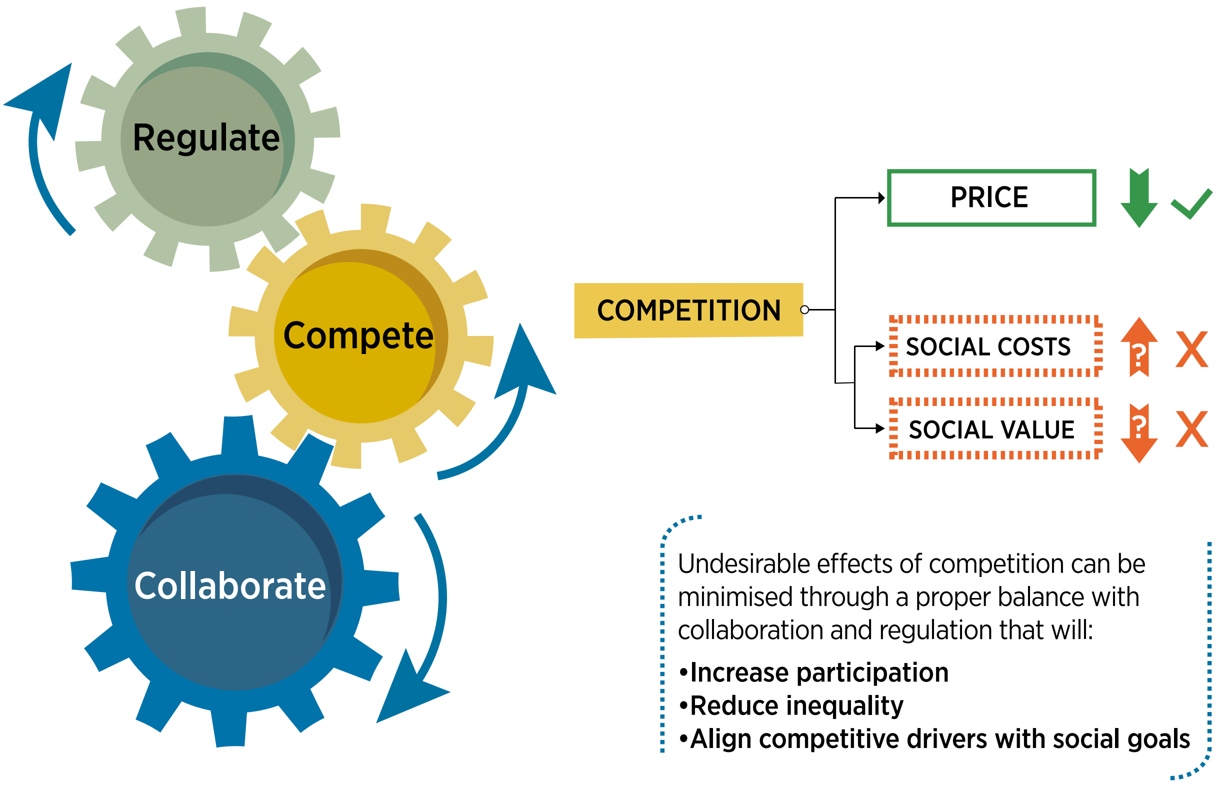
Fortunately, we are already witnessing advances in the definition of several building blocks for the implementation of such a power system structure **(e.g., Boxes 2 and 3)**. What is still needed is an integrated holistic vision of an enabling power system structure, accompanied by policy and regulatory action that make the vision a reality.

The challenge of devising a power system structure appropriate to support the post-transition power system, as well as to facilitate the transition process itself, is common to liberalised and regulated power systems. Interestingly, the transition is producing hybridised structures (Roques and Finon, 2017) all around the world.

This includes regulated support for renewable power in liberalised systems and competitive procurement of renewable power in regulated systems.

Efforts to redefine the power system structure should aim for the right balance between competition and regulation, which certainly will depend on the regional context. Those efforts should also aim to maximise collaboration[28] among stakeholders, which is increasingly being recognised as a cornerstone for a successful transition (e.g., by increasing participation and governance, reducing inequalities, unleashing the DER potential and aligning competitive drivers and regulatory approaches with social goals) **(Figure 6)**.

Figure 6. Aiming for the right balance between competition, regulation and collaboration is key for a successful energy transition



The right balance between competition, regulation and collaboration can overcome the drawbacks of liberalised as well as regulated power systems, while unleashing all of their transformative potential and synergies.

[28] There are many elements in the collaborative conceptual framework, including room for wider participation, equilibrating the roles of production and demand, shifting the microeconomic goal from profit making to social service, incorporating elements of the shared economy (Gansky, 2012) and the collaborative economy (Botsman and Rogers, 2011) and moving business models from product based to service based. The aim of this brief is not to plunge into the details of collaboration, but simply to place it in an appropriate conceptual framework.

The dual market proposal

Auctions[29] and FiT schemes have proven suitable for supporting the deployment of CAPEX-intensive renewable power plants, minimising the cost of procuring renewable power[30] by keeping finance costs low (risk mitigation). Reformed wholesale markets have also proven able to elicit investments in flexible resources. For example, the California Independent System Operator implemented two market products: the "Flexible Ramp Up" and the "Flexible Ramp Down". These provide additional flexible ramping capability to account for uncertainty arising from demand or VRE forecasting errors. Similar experiences to enable flexible resources to assist the deployment of VRE plants are becoming common worldwide (IRENA, 2017a, 2019f, 2019k, 2019m).

The "dual-market"[31] design proposal (Keay and Robinson, 2017; EUI, 2017; Forsström, Koreneff and Similä, 2016, Peng and Poudineh, 2017; Pierpont and Nelson, 2017; Nelson, 2018; Joskow, 2019; Liebreich, 2017) takes into consideration these experiences and tries to integrate them into a holistic vision of how the power system structure could be made fit for the transition. Both more liberalised and more regulated versions of it are possible, retaining the same fundamental concepts.

In the dual-market design, the traditional wholesale market is divided into two complementary markets: the **energy market** and the **delivery market.** Under this proposal, auctions become the backbone of the energy market, where energy is exchanged via long-term contracts, addressing the requirements of CAPEX-intensive technologies.

The energy market facilitates high-CAPEX investments at low capital costs, thereby minimising the cost of renewable power generation while allowing for the appropriate capacity expansion.

The delivery market, on the other hand, has the objective of procuring and affordably dispatching the flexible resources for a reliable power system. Like today's wholesale markets, it is based on marginal prices, but with a more granular bidding format and without scarcity price caps that could limit the economic feasibility of investments in flexibility. Essential characteristics of the two markets are described in Table 1. Depending on the context, there may be room to implement links between these two markets to benefit from potential synergies that would increase the value produced by the power system structure.

Both the energy and delivery markets should be designed to emit the time and locational price signals needed to maximise the synergies between the markets and the transmission and distribution grids, and so to minimise the overall cost of the power system. The delivery market must be responsive enough to enable the whole array of flexibility resources, including storage, demand-side response and sector coupling (e.g., vehicle to grid, power to X). The dual-market concept should go beyond the wholesale market to reach the retail market, so that the appropriate

[29] *In some jurisdictions, auctions are already the main instrument for the procurement of energy (Moreno et al., 2010; IRENA, 2019m)*

[30] *Other kinds of long-term risk-transfer arrangements have come into use in several power system structures. The second wave of Latin American electricity market reforms in the early 2000s introduced long-term contracts to support and co-ordinate investment in answer to investment market failures; since then, long-term investment decisions have been largely driven by auctions of long-term contracts for capacity, as in Colombia; for energy, as in Chile and Peru; or for both, as in Brazil (Roques and Finon, 2017). However, because current implementations do not resolve the misalignments discussed above, most are being re-designed to make them more conducive to the energy transition. The current long-term contracts for firm energy in Colombia, for example, do not support renewable power deployment; in fact, they are increasing the fossil fuel reliance of Colombia's originally hydro-dominated power system (Giraldo and Robindon, 2018). In Brazil, long-term auctions for new generation plants have been the resource adequacy tool used since 2004, with non-conventional renewable sources being promoted through reserve auctions; but the system is in need of an overhaul to adapt it to higher decentralisation, the shrinking of hydro storage capacity relative to electricity demand and the deployment of VRE (Batlle et al., 2018).*

[31] *At this point in the brief the original meaning of "market" as an allocation structure is recovered, departing from its neoliberal connotations of the last decades. Both more liberalised and more regulated versions are hence included within the "market" concept.*

Table 1. Characteristics of the energy and delivery markets under the dual-market system

ENERGY MARKET	DELIVERY MARKET
Based on annual long-term auctions determined by load forecasts. Designed to reliably match overall supply and demand with long-term contracts.	Based on the short-term dimension of current wholesale markets, modified to enable demandside resources, storage, the appropriate aggregation of distributed energy resources and sector coupling.
Provides investment security to minimise the finance cost of capital expenditure-intensive projects.	Designed to match supply and demand in the short/very short term.
Yields an appropriate mix of distributed and centralised generation.	Allows prices to vary from very high (need for additional generation or less demand) to very low and even negative (need for absorbing loads or curtailment).
Designed for renewable power generation technologies.	Capable to support flexibility expansion requirements (flexibility supply adequacy).
Recognises the spatial and temporal value of electricity generation as well as other elements of power system value.	Designed for flexibility resources including dispatchable renewable power storage demand response vehicle to grid and power to X.
Promotes and acknowledges social value creation.	Properly prices the spatial-temporal value of flexibility.

Source: Adapted from Pierpont and Nelson (2017); Keay and Robinson (2017).

price signals are shared with all actors, enhancing their participation in the system operation.

Within this power system structure, users may contract (possibly via aggregators) with energy producers for long-term contracts, adjusting their demand to the energy market's availability as far as possible and accepting energy at higher prices from the delivery market when needed. Moreover, through the appropriate aggregation of their DERs, aggregators can participate in both markets receiving a fair remuneration for their contributions to system operation.

Additional market structures may be required to complement the capabilities of the energy market and the delivery market, which are likely to depend on the specific configuration of individual power systems.

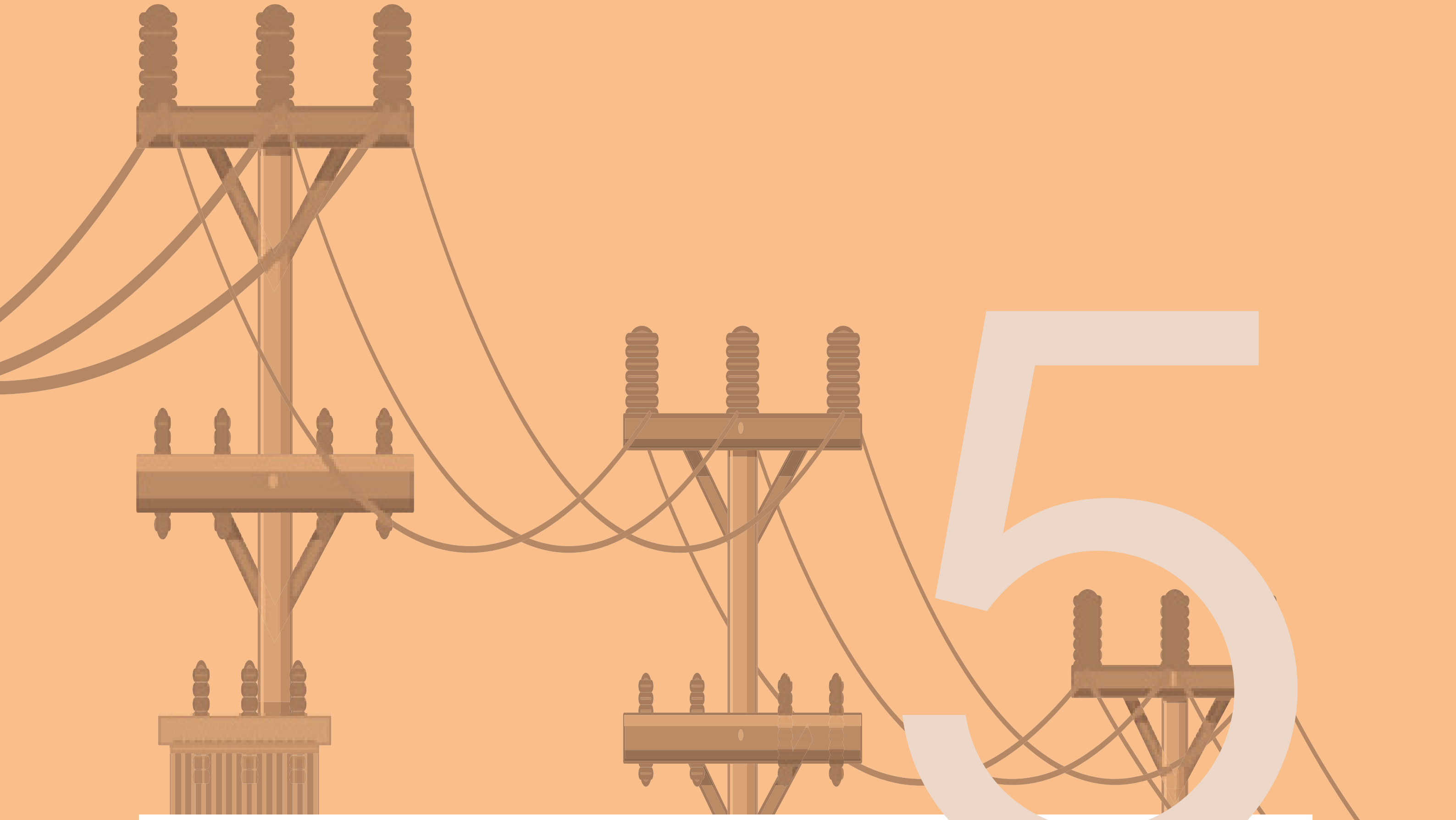
The system services market should be reformed services resources (VRE and DERs included). Fine-tuned capacity mechanisms, allowing for the participation of demand-side, distributed resources and renewable power generation, may be needed to guarantee system adequacy and reliability.

Capacity mechanisms may also be needed for flexible resources to provide long-term flexibility in the delivery market in situations where the utilisation rate and expected delivery market prices are too low or uncertain to guarantee return on investment and reasonable financing costs.

Moreover, charges and rewards for the appropriate deployment and use of grid infrastructure should be introduced and adequately shared between users and producers, with the right price signals to incentivise synergies among efficiency, generation (both distributed and centralised) and grid infrastructure – for long-term planning as well as operation.

The dual-market approach can build on accumulated experience with current power system structures and the advances that have supported the transition to date, such as FiTs, auctions and flexibility procurement.

From there, it can evolve to address the differential requirements of renewable power generation and flexibility procurement, to unleash the full potential of flexible resources, to incorporate time and locational signals, to promote system integration, and to facilitate increased participation and collaboration.



5

Conclusion

Prevailing power system structures worked well as long as the bulk of electricity was generated by centralised and dispatchable plants burning fossil fuels. Those structures must now be adapted to support the transition to a decarbonised world.

The challenge is illustrated by the misalignments between current power system structures and the policies needed to deploy renewable power generation and other DERs.

Those misalignments can produce inefficient outcomes, in the form of less renewable power and less flexibility, higher costs and social inequalities. In some areas, solutions have been found to mitigate some of the consequences of these misalignments, such as empowering aggregators or adapting the auction mechanism to procure renewables when and where they are more valuable for the system.

Still missing, however, is a holistic vision of how to transform the power system structure so that it promotes rather than hinders the energy transition. The dual-market concept recently proposed in the literature and sketched out in this brief is a step in the right direction (Pierpont and Nelson, 2017; Keay and Robinson, 2017; EUI, 2017; Forsström, Koreneff and Similä, 2016, Peng and Poudineh, 2017).

The dual-market concept takes advantage of current experiences and solutions to transform the market, yielding a structure that favours capital-intensive renewable power plants and flexible resources. Clearly, further development will be necessary for this concept to reach implementation. In the meantime, small steps can be taken by integrating and reframing elements such as auctions and more flexible wholesale markets into a broader framework aimed at delivering a future in which energy is affordable, reliable, clean and carbon free.

ANNEX A. ADDITIONAL DETAIL ON THE CASES ILLUSTRATED IN FIGURE 4

Case 1: Fossil fuel generation plant operating under a present-day system structure

This case presents a situation where the market price, aligned with the power system value, is significantly lower than the technology's levelised cost of electricity (LCOE). The assumption is that the market price reflects the real value to the power system of the generated electricity. That assumption represents an ideal case and allows the focus to shift to the structural issues related to the evolution toward a renewable-based power system.

Of course, the assumption is often not valid, since the price-setting mechanism used by the market often looks only at matching the demand with the merit order curve of the generators' marginal costs. The introduction of locational and time considerations accounting for the power broader's system requirements brings us closer to this assumption. Despite being lower than the LCOE, the market price could be aligned with and even exceed the technology's marginal costs. It would be aligned in the case where the generation plant was the average marginal plant and therefore the one whose marginal cost defines the average market price. However, for all the other plants in the system having marginal costs lower than the average marginal plant, the marginal pricing mechanism provides a buffer that could enable the plant to recover remaining costs and make a profit.

Nevertheless, the transition lowers this buffer, as discussed in the section on wholesale market misalignment, which in turn increases the demand for additional remuneration mechanisms (like capacity remuneration mechanisms).

Case 2: Renewable generation plant operating under a current power system structure, where the market price is higher than the power system value for the electricity generated.

This set of circumstances could occur during periods of high variable renewable energy generation in power system structures where locational and time-dependent factors are not captured in pricing mechanisms: Large volumes of renewable power could be generated at the wrong time and grid location, while being priced at the higher marginal cost from the marginal plant, thus straining transmission lines and forcing the power system to procure additional flexibility to maintain reliability of supply. The additional regulated payment considered in this case falls short of what is needed to attain economic sustainability.

This can occur in at least four situations:

(1) a **retroactive reduction of feed-in tariffs** (FiT) (as happened in Spain), where renewable power plants find that the FiTs under which they build their business case are retroactively reduced once the plant has been built and is operating;

(2) a **reduction in market price** during the operational life of a plant operating under a premium FiT or power purchase agreement, for instance, as a consequence of the cannibalisation effect associated with deploying increasing amounts of renewable energy under the current power system structures;

(3) a **power position in competitive bidding** that leads contractors to bid power purchase agreements too low to cover the real LCOE (e.g., to gain market share or displace smaller competitors from the market); and

(4) the presence of **other subsidies** (e.g., under industrial policies designed to promote a given technology), which reduce the LCOE as perceived by the bidder below the real LCOE.

GLOSSARY

Capacity remuneration mechanism: Market instruments or regulated payments designed to ensure sufficient system adequacy and reliability by providing capacity-based payments to encourage investment in new capacity or to allow existing capacity to remain operative.

Capital expenditure: In the energy sector, this term refers to the costs incurred to design, build and commission a power plant. More generically, it refers to all the costs incurred before the plant's operational phase begins.

Delivery market: The component of the dual-market approach that addresses the procurement and dispatch of flexibility.

Distributed energy resources: Small-size energy technologies that are located in the distribution grid or behind consumers' meters. They encompass renewable power technologies, storage and demand response resources.

Dual market: An approach to aevolve the current power system structures to better suit the characteristics of a renewable-based power system. This is done by dealing with the different requirements of procuring electricity generation from renewables and procuring flexibility with two different structures: the energy market and the delivery market.

Energy market: The component of the dual-market approach that addresses the procurement of electricity generation.

Grid defection: The phenomenon of one or more customers disconnecting from the grid entirely and relying on self-produced power.

Levelised cost of electricity: The annualised life-cycle cost of generating electricity with a specific power plant.

Load defection: The phenomenon of one or more customers shifting part of their load from utilitydelivered electricity to their own self-generated power.

Misalignments: For the purposes of this brief, "misalignment" is used to define a situation in which two or more policies combine to produce an unintentional outcome that is inefficient or otherwise undesirable.

Net metering: An energy accounting procedure by which prosumers can balance electricity generation and consumption through their meter, which allows consumers who generate some or all of their own electricity to use that electricity at any time, instead of when it is generated. This is an enabling policy designed to foster private investment in renewable energy.

Operational expenditure: In the energy sector, this term usually refers to operation and maintenance and fuel costs.

Opportunity cost: The opportunity cost of generating one unit of electricity at a given point in time is defined by the revenue forgone by not generating it at another time (positive opportunity cost), or the revenue lost (or additional cost incurred) by not generating a unit of electricity at a given point in time (negative opportunity cost). Both conventional and renewable generation plants can have positive and negative opportunity costs. Examples of drivers of negative opportunity costs are takeor-pay natural gas contracts for gas-fired power plants, and production tax credits or renewable energy certificates for renewable power plants.

Power to X: Technologies that allow the decoupling of power from the electricity sector for use in other sectors through the conversion and storage of energy in the form of fuels (either liquid – P2L or gaseous – P2G), typically obtained through hydrogen produced with renewable-based electricity, or heat (power to heat – P2H) The reverse conversion from X to P can be used to provide generation flexibility to the power sector.

Power system structure: For the purposes of this brief, "power system structure" refers to the organisational structure of the power system, encompassing both the market mechanisms behind liberalised power systems and the organisational structures of regulated power systems. The term "power market" is equivalent to "power system structure" for a liberalised power system. However, because this brief broadly addresses both the liberalised and non-liberalised contexts, the term "power system structure" is used throughout.

Power purchase agreement: An agreement guaranteeing the remuneration of a generator over a long period based on defined conditions.

Social value: The full value to society of generated electricity, including its value to the power system in view of its locational and temporal characteristics. But it goes beyond that to include the additional social value, addressing the full socio-economic value of the generated electricity. The value beyond the power system includes, among others, aspects like stimulation of economic activity, coverage of services beyond what is priced in the market, provision of quality jobs, contribution to democratise and improve the governance of the energy system, reduction of pollution and related health and ecosystem impacts and mitigation of climate change.

System adequacy: The ability of a power system to cope with its load in all the steady states it may encounter under standard conditions.

System flexibility: The capacity of a system to make adjustments to balance supply and demand over different timescales, from seconds to months.

System services: Those services, other than energy, that are necessary for the secure operation of the power system (frequency regulation, reactive power and voltage control, operating reserves). Also referred to as ancillary services.

Vehicle to grid: Bidirectional interaction between electric vehicles and the grid, using vehicle's batteries as distributed storage.

Variable renewable energy: Wind, solar photovoltaic (PV) and wave power.

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