IRENA

International Renewable Energy Agency

RE-organising power systems for the transition

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ABOUT IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that serves as the principal platform for co-operation, a centre of excellence, a repository of policy, technology, resource and financial knowledge, and a driver of action on the ground to advance the transformation of the global energy system. 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. www.irena.org

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FOREWORD

Together, we must embark upon a rapid and sustained energy transition to avoid the deeply disruptive impacts of the climate crisis. As outlined in IRENA's flagship World Energy Transitions Outlook 2022, the power sector lies at the heart of this transition, which requires increased electrification of end uses and the adoption of variable renewable energy (VRE) such as wind and solar PV as the main sources of electricity. In this context, it is essential to establish robust structures to guide the procurement of electricity and ensure the flexibility required for a just and sustainable renewable era.

Today's power systems, structured around large centralised and dispatchable power plants, require more than 'quick fixes'; rather, a holistic approach is required to address all key aspects – from technology and economy to society and the environment. Otherwise, misalignments between electricity procurement mechanisms, regulations and policies will continue to hinder a successful energy transition.

These misalignments have drawn considerable political and media attention in recent years, particularly in response to the sharp decrease in energy demand amid the national lockdowns of the COVID-19 pandemic. While this paved the way for a higher share of variable renewable energy in the power mix, electricity prices fell to such levels as to create barriers to merchant renewable plants.

Conversely, during the more recent natural gas supply crisis, marginal fossil fuel generators in liberalised contexts have raised electricity prices to unforeseen levels, diverting the focus of policy actions away from the barriers to the energy transition posed by low-price events.

Against this background, *RE-organising power systems for the transition* aims to inform discussions on the role of power system organisational structures in facilitating and accelerating the energy transition. It discusses enablers and barriers to the transition, including misalignments inside and outside power systems, as well as the role of competition and its balance with regulatory and collaborative components.

The report also outlines a power system organisational structure fit for the renewable era that can support low-cost renewable generation and long-term investments in system adequacy, complemented by diverse flexibility options to ensure a reliable power system.

I am confident that the insights offered by this report will prove useful in informing much-needed discussions on this essential aspect of the energy transition.

Francesco La Camera
Director-General, IRENA

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GLOSSARY

- **Energy poverty:** When a household is unable to secure a level and quality of domestic energy services sufficient for its social and material needs, impairing its socio-economic development.
- **Energy vulnerability:** The propensity of being unable to meet essential energy services. An energy-vulnerable household, when an increase in power price occurs, may land in an energy poverty situation.
- **Grid defection:** The process through which one or more users defect from the power grid, adopting distributed resources and storage for their electricity needs.
- **Misalignments:** Defined here as the unintentional inefficient outcomes of the interaction between renewable power generation policies and the design of the power system's organisational structure, as well as the intrinsic incapability of current organisational structures to foster and sustain a power system based on renewable generation.
- **Power system organisational structures:** A term used to refer to the systems, institutions, procedures and social relations through which electricity services are exchanged and rewarded. It encompasses all systems, from liberalised power systems (based primarily on market mechanisms) to vertically integrated systems. For a liberalised power system, the term "power market" is equivalent to "power system organisational structure". This report aims to inclusively address all power system structures, liberalised and regulated, because the main transition challenges are common to all of them.
- **Pro-user:** Any user of the power grid able to both use and produce electricity with its own means, also referred to as prosumer. The terms "pro-user" and "user" are adopted to highlight the active role of people in the power system, beyond the passive role traditionally recognised as "consumers".

ABBREVIATIONS

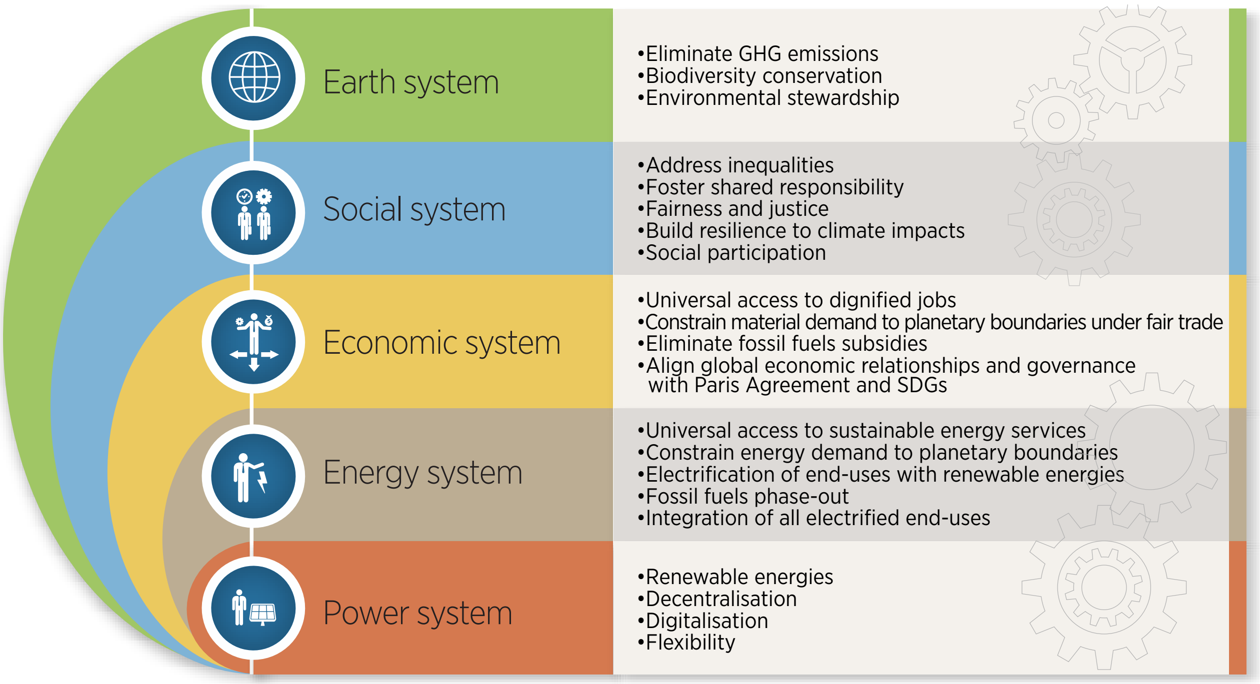
BAU	business as usual
CO_2	carbon dioxide
°C	degrees Celsius
CAPEX	capital expenditure
CEC	custo esperado de compra
CSP	concentrating solar power
CVPP	community-based virtual power plant
DSO	distribution system operator
EFR	enhanced frequency response
EI	energy intensity
EMI_E	CO_2 emissions intensity of energy
EJ	exajoule
ENTSO	European Networks of Transmission System Operators
EPC	Engineering, procurement and construction
ESC	Essential Services Commission
EU	European Union
GCC	Gulf Cooperation Council
GDP	gross domestic product
Gt	gigatonne
GWh	gigawatt hour
IPCC	Intergovernmental Panel on Climate Change
IPP	independent power producer
IRENA	International Renewable Energy Agency
ISO	independent system operator
LCOE	levelised cost of electricity
LT-RE	long-term renewable energy
MW	megawatt
MWh	megawatt hour
OECD	Organisation for Economic Co-operation and Development
OPEX	operating expenditure
OTC	over-the-counter
PES	planned Energy Scenario
PPA	power purchase agreement
PV	photovoltaic
REMAP	IRENA's energy transition roadmap
SR1.5C	IPCC Special Report on the impacts of global warming of 1.5°C
ST-Flex	short-term flexibility
TES	transforming Energy Scenario
TSO	transmission system operator
TYNDP	Ten-Year Network Development Plan for Energy Infrastructures
TWh	terawatt hour
TWH	terawatthour
USD	United States dollar
VIU	vertically integrated utility
VOLL	value of lost load
VRE	variable renewable energy

EXECUTIVE SUMMARY

Power systems are at the heart of the energy transition, and their organisational structures will determine to a great extent how the energy transition progresses. However, power system organisational structures themselves need to transition, evolving from the fossil fuel era to become fit for the renewable energy era. This dimension of the energy transition has often been overlooked.

Discussion on this topic has been mainly limited to power system specialists from developed countries. As a consequence, it is often biased towards liberalised contexts and is narrowly focused on the power system layer itself. However, a successful transition hinges on collaborative efforts with a global dimension, requiring deep, active and informed participation from all countries reflecting different socio-political contexts. A holistic approach is needed that addresses the interactions across the different systemic layers: power, energy, economy, social and Earth (Figure S-1).

Figure S-1. Cross-cutting transformations for a fair and just energy transition from the power, energy, social, economic and Earth systems



Note: GHG = greenhouse gas; SDGs = Sustainable Development Goals.

This report aims to fill these gaps by addressing the transition requirements of power system organisational structures, with a holistic vision and an inclusive approach that is applicable in both liberalised and regulated contexts. For this purpose, the report is structured around two main goals:

1) making the discussion about power system organisational structures and their transition requirements accessible to a wider audience, as well as contextualising it within a systemic vision; and

2) presenting and discussing the transition challenges for power system organisational structures and proposing a way forward that matches the requirements needed for the renewable energy era.

The report is structured in two parts. The first part (chapters 1-3) addresses the first goal, providing a holistic vision of power system organisational structures in a transition context. It provides the systemic vision and inclusive context for the second part (chapters 4-6), which focuses on the transition challenges of power system organisational structures and a potential way forward. Hence, the first part of the report may benefit even readers who are well acquainted with the fundamentals of power system structures.

Part I: A holistic vision of power system organisational structures in a transition context

The energy transition is a must and the power system a cornerstone of it

The report lays out the contextual framework for the energy transition and the role that power system organisational structures play in it. It highlights the relevance of a systemic approach that captures the interactions between the different systemic layers (power, energy, economy, social, Earth) and the role of power systems in these dynamics.

Despite growing evidence of human-caused climate change, greenhouse gas emissions have continued to grow. If left unchecked, those emissions could warm the Earth as much as 4-5 degrees Celsius on average before 2100, causing significant damage to the environment and to socio-economic systems, with consequences for the human populations that depend on them. Policy makers and society have taken steps to address the climate emergency, but reducing carbon emissions in line with the requirements of the challenge will require an unprecedented transition in all parts of society, including in energy, land use, urban life and infrastructure use; in the industrial sector; and in the economy. Each of these essential pieces of the global transition calls for committed policy making and enhanced governance.

The technological layer of the energy transition – shifting from fossil fuels to renewable energy, energy efficiency and flexibility – is the most advanced, although it is still insufficient for successfully addressing the climate crisis. Other transition layers are less advanced, such as the systemic changes layer that addresses the evolution from today's centralised, non-integrated energy systems in which only a small number of stakeholders directly participate, towards more distributed, integrated energy systems in which many users participate through enhanced governance. Progress is being made in addressing this layer, although slowly.

A third transition layer that underpins progress in the other layers, but that lags in informed discussion about its transition requirements, is power system organisational structures (Figure ES-2). Putting in place the appropriate organisational structures for the renewable energy era is essential to allow the other transition layers to prosper. The organisational structures upon which our socio-economic system operates may be key enablers of or fundamental barriers to the needed transition.

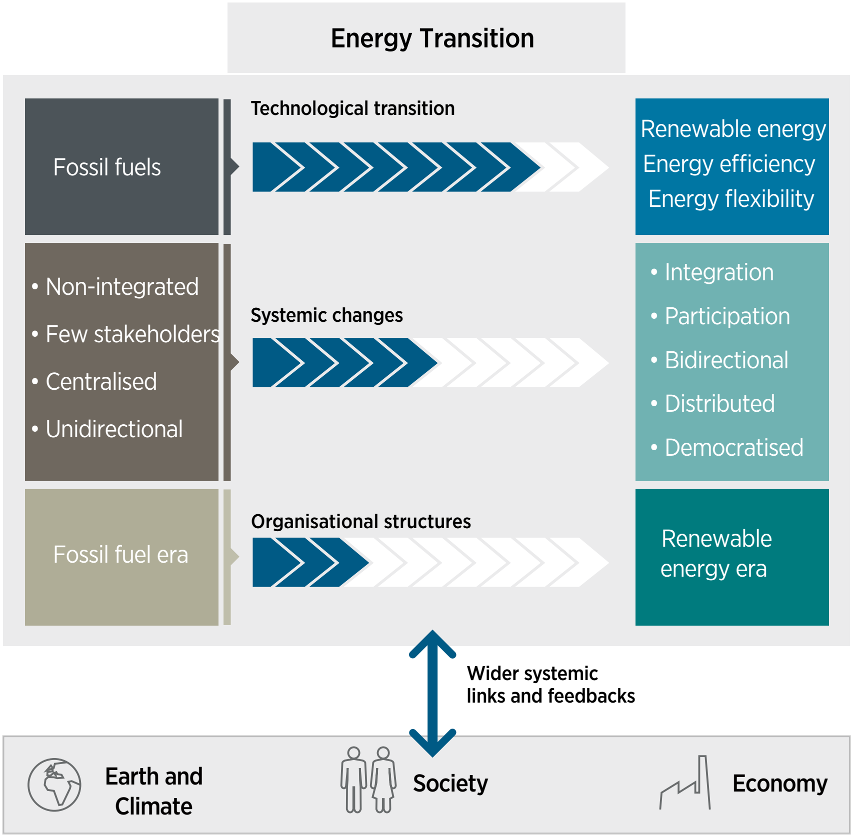
Power systems will be greatly impacted by the energy transition

As the energy transition unfolds, it will bring both challenges and opportunities for power systems. Implications of the transition include the dominance of variable renewable energy (VRE) generation, increased diversity in flexibility requirements and sources, more distributed energy resources, a more active role for the users of the power grid, and a boost in data gathering and exchange supported by digitalisation.

Contextualising power system organisational structures

Power system organisational structures have evolved along different pathways depending on the prevailing socio-political frameworks, across time and jurisdictions. Elements of today's existing structures will facilitate addressing the transition requirements. An inclusive approach is used throughout the report, acknowledging the fact that challenges and goals are found across different organisational structures, the appropriate transition pathway will be case-dependent. All of the socio-political frameworks are capable of offering value for a successful transition.

Figure S-2. Unequal advance in different layers of the energy transition, with organisational structures lagging



To achieve its goals, a power system organisational structure should anticipate and procure the needed capacity and infrastructure, as well as produce and deliver electricity within the existing socio-economic and environmental boundaries. Today's structures were conceived and put in place to meet the goals of the fossil fuel era. Now they need to adapt to the requirements and context of the energy transition.

The dichotomy between "regulated" and "liberalised" power systems, although commonly used, can be misleading. For example, in recent decades the deployment of renewables in liberalised systems has occurred largely through regulated payments and re-introduced regulation for dedicated and state-driven procurement of specific technologies, overriding competitive markets. This situation was not new: since the origin of power systems, support mechanisms and dedicated policies have been adopted for technologies deemed to be strategic. Meanwhile, regulated systems can also incorporate competitive components such as auctioned power purchase agreements with independent power producers, or tenders to build new renewable energy infrastructure.

The deployment of merchant power plants is far from becoming a common occurrence. Indeed, under the misalignments emerging from current power system organisational structures, such deployment does not seem feasible at the scale required by the energy transition.

Part II: Enabling the transition of power system organisational structures

Understanding existing and potential future misalignments

Developing power system organisational structures that are appropriate for the energy transition requires having a clearer understanding of existing and potential misalignments,[1] since overcoming these is the goal of improved organisational structures. Many diverse misalignments exist today, with wide-ranging causes and effects across the different systemic layers.

Energy systems are set up to provide energy services to society; however, delivering those services can result in undesirable impacts on societies. Important misalignments have led to serious consequences. For example, climate change and air pollution are among the unwanted effects that result when the organisational structures of the fossil fuel era fail to properly align the cost, price and value dimensions of energy. Although the energy transition is expected to mitigate both climate change and air pollution, as the transition progresses new fundamental misalignments may arise and others remain; if unaddressed, these can trigger transition barriers and/or limit the benefits that society might reap from the transition.

Misalignments within the power sector spur from differences in technological characteristics between conventional and transition-related resources. All power systems, from the more regulated to the fully liberalised, will face them.

Although renewable energy support mechanisms have evolved to become more "system-friendly" over time, **the fundamental disconnect between organisational structures and the specific techno-economic characteristics of renewables** has not been addressed. Evidence of such misalignments has triggered regulatory measures aimed at fixing them. However, by failing to address the bottom-line issues, these temporary fixes do not prevent misalignments from resurfacing as the deployment of renewables advances.

A clear example of misalignment in the power system is **the decline in electricity prices during periods of high VRE penetration**. This reduces the returns for VRE systems that earn revenue from wholesale markets in liberalised systems, and hence discourages further investments without appropriate support.

Today's **wholesale pricing structures** (which rely on marginal costs) **are not appropriate for renewable-based power systems.** An organisational structure that relies on marginal costs is unable to support a renewable-based power system once the current additional regulated payments are phased out. The mainstream policy narrative argues that as renewables become cost competitive, such payments should be ended. However, once the revenue for VRE power plants is limited only to that from marginal pricing structures, the extremely low wholesale electricity prices that result from high penetration of renewables compromise the very business case for these plants. This, in turn, leads to an increased risk perception that directly translates into higher capital costs, hence preventing renewable generation from delivering its potential for low-cost electricity. Such a situation – where the success in deploying renewable energy undermines its future viability because of wholesale price depletion – is known as the "cannibalisation effect".

Misalignments also may arise in the flexibility dimension. **Policy makers must ensure that capacity mechanisms are used for their original purpose** – to maintain system reliability – rather than leading to transition barriers by keeping online rent-seeking fossil fuel power plants that eventually will need to be phased out during the energy transition. Capacity remuneration mechanisms, if deemed necessary for supporting flexibility investments to maintain system reliability, should be designed recognising

[1] In the power system layer, the term "misalignment" refers to the negative unintended consequences of the interaction between renewable power generation policies and the design of power system organisational structures, as well as the intrinsic incapability of current organisational structures to foster and sustain a power system based on renewable generation.

the system and social value from all flexibility resources (on both the supply and demand sides), within a transition context and within the framework of an organisational structure that is fit for a renewable-based power system.

Power system structures need to be designed to provide electricity to all while supporting an ambitious, cost-effective, fair and just energy transition, spurring innovation in technology, enabling all users to become real actors of the power system, and contributing to building the resilience needed to navigate socio-economic and environmental challenges.

If VRE is to become the main source of power, electricity prices should no longer be determined based on how well the system compresses fuel costs. Instead, the main goals of the power system become: 1) financing VRE plants (which have high capital expenditures, or CAPEX); 2) procuring the needed flexibility. Fostering participation and improving governance are cornerstones to triggering the collaborative effort required for the transition.

Electricity billing plays an important communication role. Hence, the billing structure needs to be updated to clearly communicate the meaning and implications of each component to end users, as well as aligning it with the characteristics of a renewable-based power system.

Misalignments beyond the power system also need to be addressed, using a holistic transition planning and policy framework. Most of these misalignments existed prior to the energy transition, having long co-existed with fossil fuel-based power and energy systems. However, today's critical environmental and social framework makes addressing these misalignments fundamental to a successful energy transition.

Misalignments associated with issues of **labour, unlimited growth and inequality** will not be sorted out by merely transitioning to a power system based on renewable sources. Moreover, an unjust energy transition can create social resistance, as is already happening in some jurisdictions. Hence a holistic policy framework that spans all of the systemic layers will be needed to address such misalignments and to prevent the transition barriers that these issues could produce.

Our current socio-economic structures enter a crisis stage when we shift away from the economic growth imperative. However, seeking to maintain the global economy on a path of unlimited growth makes it far more difficult to comply with ambitious climate goals that prevent catastrophic impacts on our socio-economic system. Hence addressing structural aspects that allow our socio-economic systems to progress and thrive beyond the growth imperative is becoming a priority. A steady-state economy that properly addresses distributional aspects seems an appropriate goal for human activity on a planet that has finite resources and impact-bearing capacity.

Addressing the climate emergency requires an unprecedented global collaborative effort. Triggering and maintaining such an effort requires a solid social contract that leaves no one behind. Hence inequality is an important misalignment of today's socio-economic system that can seriously hinder the success of the energy transition. Beyond solidarity, in the current climate crisis addressing the distributional dimension has become a must. Transition dynamics in an unequal and unfair world would lead to much of the world's population getting access to very cheap fossil fuels and related technologies, because of the reduced demand for these from the global North. This could easily reverse any decarbonisation advancements in the global North as the rest of the world seeks to replicate its fossil fuel-based economic growth of the past decades.

Searching for the right balance among competition, regulation and collaboration

The three main components shaping power system organisational structures are competition, regulation and collaboration.[2] Given the prevailing role of liberalisation in shaping organisational structures in recent decades, these three components have pros and cons, creating the need for a case-dependent balance that maximises the overall transition benefits within each socio-political context.

Power system structures commonly range from “regulated” to “liberalised”.[3] In regulated structures, a single utility owns and operates the full set of infrastructures needed to generate, transmit and distribute energy. In liberalised structures, generation and retail of electricity are open to competition, with customers being able to choose the electricity provider among available market choices.

In recent decades, a sustained global effort has been made to liberalise power systems worldwide, promoting market-based, profit-driven competition procurement and allocation mechanisms in systems that were formerly public, centrally planned and vertically integrated. This has been part of a broader trend where liberalisation is considered the preferred pathway to introduce economic efficiency in most sectors, including power systems. In practice, however, liberalisation reforms of power systems have proved difficult to apply universally, leading to a wide range of hybrid solutions between liberalised and regulated systems.

The energy transition is now introducing further hybridisation, for example through regulated support for renewable power in liberalised systems and through competitive procurement of renewable power in regulated systems. Based on projections, in a few decades most of the global population will live in regions where regulated power systems are currently prevalent. Hence it is worthwhile to explore whether competitive, profit-driven markets are the only valid option to advance procurement mechanisms, and under which circumstances these can be enablers or barriers for the needed energy transition.

Notably, the drivers that in the past led to the predominance of regulated systems – such as intense grid expansion needs and a post-World War II reconstruction context – are gaining traction today as the transition progresses and socio-economic challenges are high on the agenda.

Competition, together with independent regulators and good governance mechanisms in favourable socio-economic and political contexts, has proved to contribute to improving the overall efficiency and financial viability of utilities, while facilitating a better environment for investment during the fossil fuel era. However, even within the fossil fuel era, when profit-driven competition was introduced with weaker starting conditions, such competition has seldom led to positive results, even increasing the risk for policy turnabout. Furthermore, even the best-structured competition-driven organisational structures have proved unable by themselves to deliver on key social and environmental imperatives (long-term renewable energy adequacy, fossil fuel phase-out, etc.). Additional policy measures have been essential to redirect and promote the needed investments for energy access and the energy transition.

Moreover, several countries have shown that it is possible to achieve comparable power system performance without pushing the liberalisation agenda. For example, both Costa Rica and Uruguay have competent state-owned vertically integrated utilities (VIUs) guided by clear policy goals, combined with a more gradual and targeted role for the private sector. This approach has allowed regulated state-owned power systems to improve the operation of utilities while maintaining the ability to deal

[2] Collaboration is defined here as the ability to act collectively to achieve a common societal goal.

[3] Note that liberalised structures also require strong elements of regulation in order to align markets with power system and social goals, including addressing externalities, to the point that some authors use the term “re-regulation” to refer to liberalisation dynamics. However, for the sake of brevity the “regulated” versus “liberalised” nomenclature is used in this report to designate the two extremes in organisational structures.

with the power system as a whole and to capture wider socio-economic system interactions. Such an integrated approach offers advantages when addressing deep transformation requirements within limited time frames, such as the energy transition that is needed to address the climate crisis.

In practice, however, neither public vertical integrated utilities nor liberalised competitive systems are socio-economically efficient and sustainable by default. Both can be captured by bureaucracy and inefficiency or even by vested interests. Thus, whatever the chosen pathway (regulated, liberalised or hybrid), a successful transition depends on strong, high-quality governance, inviting the adoption of a more pluralist view regarding the available options to deliver climate-proof outcomes in each socio-economic context. Governance, in turn, requires advanced forms of collaboration among all agents, and specifically of social participation where society can directly and indirectly take part in decision making, including in defining organisational structures and aligning them with the power system, social and environmental goals.

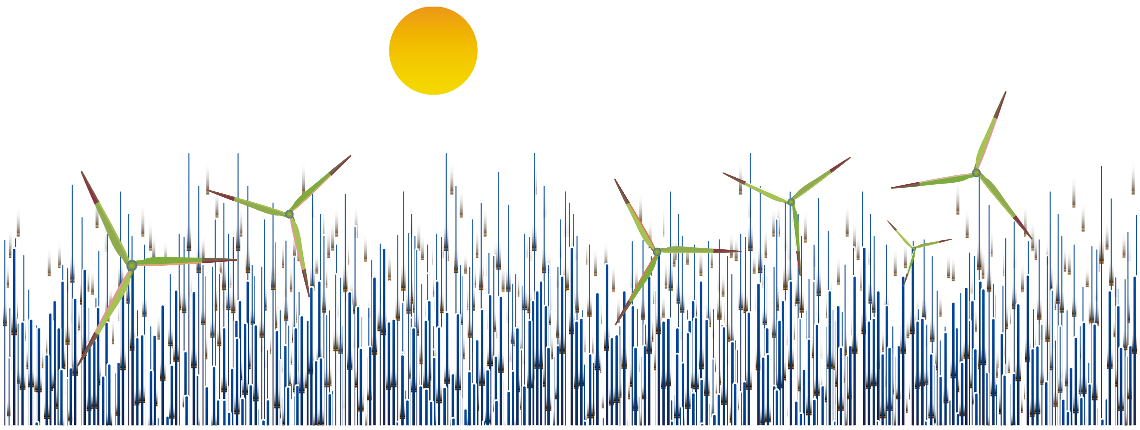
Under the current context, both regulated and liberalised components may have space to contribute to the energy transition and to address current challenges. Hence it seems worthwhile to search for synergic combinations of liberalisation and regulation that can deliver for the challenges ahead in different socio-economic contexts.

The COVID-19 pandemic has shown that societies can pursue bold action in complex situations when taking steps collaboratively – but also that this cannot be taken for granted and that significant improvements in governance to address global challenges are needed. Therefore, beyond regulation and competition, power system organisational structures need to consider how to foster collaboration to accelerate the energy transition while maximising its socio-economic value.

Materialising the required collaborative effort needed to address the climate crisis requires building a framework of trust, where citizens perceive that good governance is in place, that no one will be left behind, and that the burden and benefits of the transition are fairly shared.

The way forward: dual procurement of renewable electricity and flexibility

An initial proposal of a way forward for power system organisational structures is the "dual procurement". The **dual procurement approach acknowledges the different characteristics and requirements of the two main elements that the power system needs for a successful energy transition** – *i.e.* renewable electricity and flexibility[4] – as well as the need for holistic integration of both of these elements within the power system and with the other systemic layers.



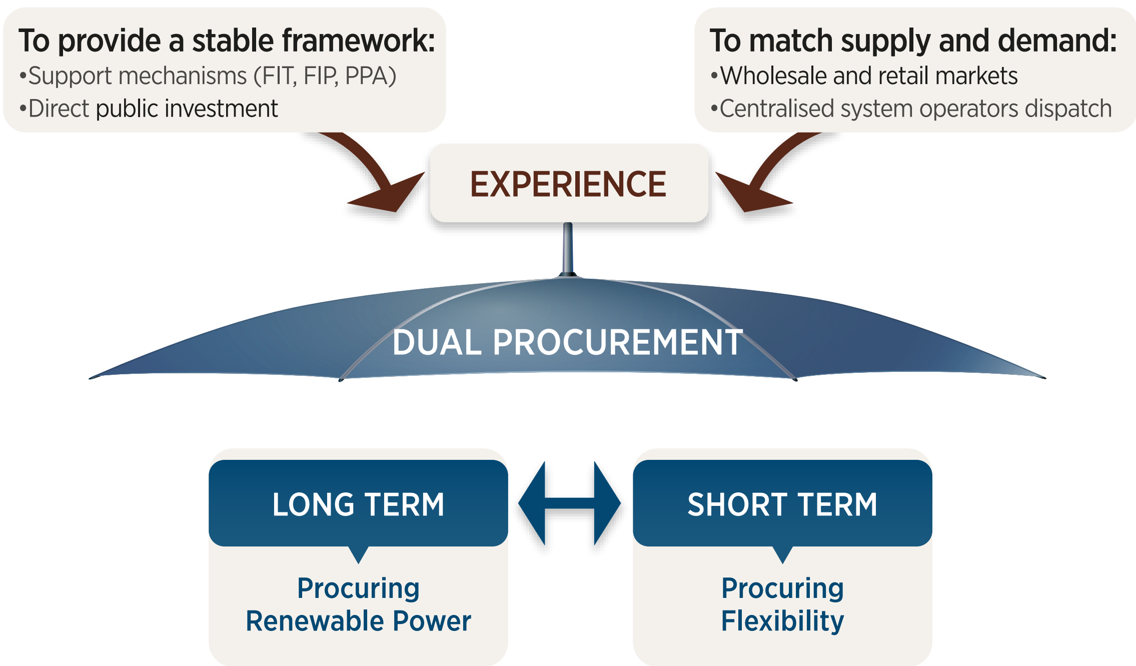
[4] The report focuses on two main pillars of the needed power system organisational structures: procuring renewable electricity, and flexibility; hence the use of the term "dual procurement". However, a complete power system organisational structure has other elements beyond these two main ones, such as ancillary services procurement, which in turn will also interact with the two main pillars.

The time has come for a power system organisational structure that can support the energy transition and the power systems of the future. The good news is that it does not need to be produced from scratch. The instruments that have proved capable of supporting the energy transition up until now, if integrated properly, are appropriate bricks for building the needed structure. For example, power purchase agreements, feed-in tariffs and public direct investment schemes have proved suitable for supporting the deployment of CAPEX-intensive renewable power plants, minimising the cost of procuring renewable power by keeping finance costs low. Meanwhile, temporal and spatial granular wholesale markets have proved able to elicit investments in flexible resources.

The dual procurement approach takes into consideration these past experiences and integrates them into a holistic vision of how the power system structure could be made fit for the renewable energy era (Figure ES-3). Separately, although in a co-ordinated fashion, dual procurement procures both renewable energy and flexibility while honouring the different characteristics of both. **The two main procurement mechanisms are long-term renewable energy (LT-RE) procurement and the procurement of flexibility[5] (ST-Flex and LT-Flex)**.

A conceptual shift introduced in the dual procurement approach is to make long-term electricity procurement schemes one of the two main pillars, hence acknowledging that they are here to stay. By separating the LT-RE and ST-Flex procurements, one of the main issues with unlimited scarcity pricing is directly addressed: during a scarcity event, not all generation will be rewarded at the scarcity price; rather only the generation and demand components supplying the required flexibility will be rewarded at this price, thereby minimising the chance of generating windfall profits.

Figure S-3. The dual procurement concept



[5] The procurement of flexibility is likely to require both short-term (ST-Flex) and long-term (LT-Flex) mechanisms, with the mixture of both evolving as the transition progresses and being dependent on the prevailing socio-political context in each jurisdiction. The report's narrative assumes that ST-Flex will be the dominant mechanism in the long term, with LT-Flex complementing it as required at different points in time and jurisdictions, just as capacity mechanisms are doing today. However, the appropriate mix of ST-Flex and LT-Flex remains a design variable to align each power system organisational structures with its specific context.

Auctions or direct public investment become the backbone of LT-RE procurement, through long-term procurement mechanisms that address the requirements of CAPEX-intensive technologies. ST-Flex procurement addresses procurement of the flexible resources needed for the reliable operation of a renewable-based power system, and is based on marginal prices, with a granular bidding format. Essential characteristics of the two procurement mechanisms are described in Table ES-1.

Table S-1. The pillars of dual procurement: Long-term renewable energy (LT-RE) procurement and short-term flexibility (ST-Flex) procurement

LT-RE procurement	ST-Flex procurement
Based on periodic, long-term product-based allocation mechanisms (auctions, direct public investment, etc.).	Based on the short-term dimension of current dispatch mechanisms (balancing markets, regulated dispatch, etc.).
Procures renewable electricity (VRE and dispatchable renewables) and enables renewable energy supply adequacy with the adequate anticipation.	Procures flexibility (demand-side management, distributed energy resources, storage, dispatchable renewables, power-to-X, vehicle-to-grid, etc.) and enables flexibility supply adequacy.
Designed to match supply and demand as much as possible in the long term (capturing temporal and locational value to the power system).	Matches supply and demand in the short and very short term (capturing temporal and locational value to the power system).
Driven by long-term load forecast within integrated energy planning.	Driven by short-term and very-short-term deviations between the scheduled load / renewable energy production and real demand/ production.
Provides a safe investment environment that minimises finance costs for CAPEX-intensive technologies.	Liberalised systems: Allows prices to vary from very high to low and even negative, and allows for additional regulated payments if needed (especially during the transition period: LT-Flex). Regulated systems: Provides an enabling framework for deploying and operating the required flexibility capacity.
Designed for the characteristics of renewable energy technologies.	Designed for the characteristics of flexibility resources including dispatchable renewable power, storage, demand response, vehicle-to-grid and power-to-X.
Recognises the spatial and temporal value of energy.	Recognises the spatial and temporal value of flexibility.
The economic signals of dual procurement should reach the retail rates (or prices) of all users to promote their participation in system operation, while simultaneously addressing distributional issues so that collaborative engagement is achieved in a just transition.	
Society-wide collaborative governance (public or private), promoting and acknowledging social value creation: Enables effective societal and user participation in planning and operation, fostering the required collaborative framework for social value creation.	

LT-RE procurement is designed to match supply and demand as much as possible in the long term, in both the temporal and spatial dimensions, using renewable energy and facilitating the investments needed to guarantee adequate electricity supply in the system.

ST-Flex procurement is designed to match supply and demand in the short and very short terms, allocating flexibility resources to meet the deviations between the scheduled load and renewable energy production and the real-time load and production. ST-Flex procurement is based on the short-term dimension of current marginalist allocation mechanisms (short-term wholesale markets, balancing markets, short-term cost-based markets, regulated dispatch, etc.) modified to be more flexible and responsive. It enables the activation of demand-side resources, storage, the appropriate aggregation of distributed energy resources, and sector coupling when needed, and facilitates the investments needed to ensure flexibility supply adequacy.

Both LT-RE and ST-Flex procurement recognise the spatial and temporal values of electricity and flexibility. They also promote and acknowledge social value creation beyond the power and energy systems.

Demand plays a critical role in both procurement mechanisms to shape long-term forecasts and to actively provide flexibility services. Therefore, in this proposal users are enabled to participate in the procurement mechanisms directly or indirectly, becoming decision makers and information providers in design and planning, as well as actors in provisioning both renewable electricity and flexibility at distributed and large scales.

Conducive retail rates and prices are essential to facilitate distributed investment in renewable energy or flexibility assets and to activate its services when needed. Therefore, the dual procurement concept should go beyond the generation and flexibility allocation mechanisms and reach the retail sphere. Appropriately sharing economic signals with all actors enhances their participation in the design and operation of the power system.

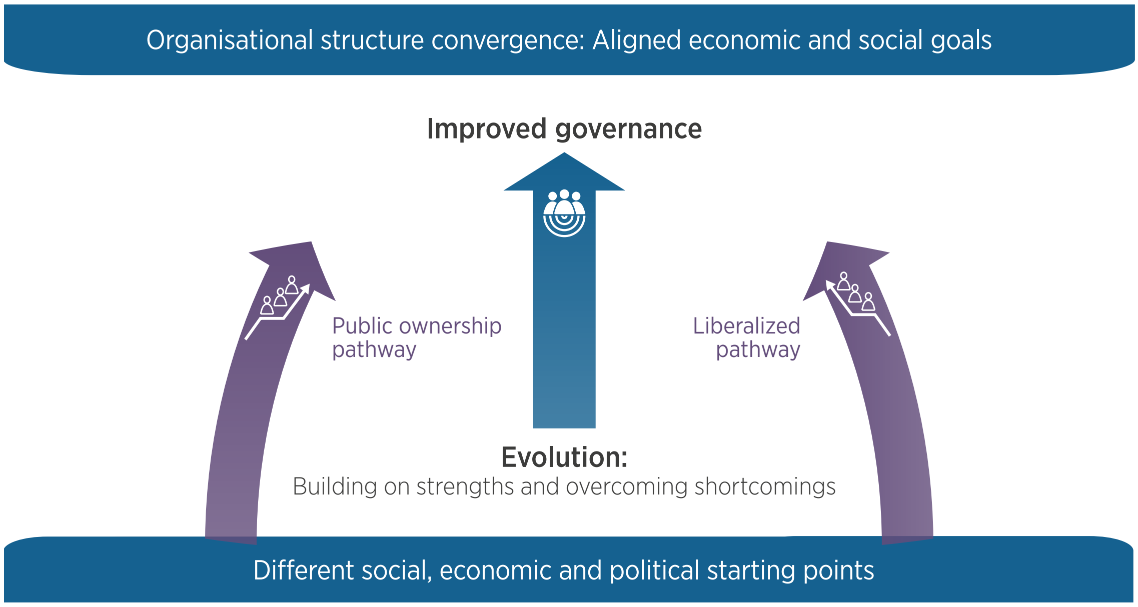
Within the dual power system structure, users may contract with renewable energy producers for long-term contracts, adjusting their demand to the LT-RE availability as far as possible, and accepting energy at higher prices from the ST-Flex procurement mechanism when needed. Through the appropriate aggregation of their distributed energy resources, users can participate in both procurement mechanisms, receiving a fair remuneration for their contributions to system operation.

The existing socio-economic context has proved to be critical for shaping current power system organisational structures. The dual procurement proposal applies to both liberalised and regulated systems, as well as hybrid systems, with each jurisdiction requiring its context-specific mix of collaboration, regulation and competition for its implementation. Indeed, implementation of the dual procurement proposal should focus on improving governance to overcome the current failures of both liberalised and regulated systems:

- The most liberalised versions would improve by taking measures to avoid market failures such as market power abuse, elements of speculative action or ignoring externalities, and improving governance to reach a better alignment with social value.
- More regulated versions would benefit from opening to the wide diversity of stakeholders and resources that could participate in the transition, working to get better access to information on the costs of power and flexibility plants, and improving governance to trigger active social involvement.

In both cases, there is a need to create new ways of addressing prosperity, balancing environmental and human rights together with the economic performance of the dual procurement mechanisms. In the long run, **a certain degree of convergence** in the implementation of the dual procurement proposal under regulated or liberalised contexts **should be expected**, since they share the main aim and the means to improve how to reach it (Figure ES-4).

Figure S-4. Convergence of organisational structures following the liberalised and public ownership pathways



The systemic change approach addresses the requirements of the structures needed by renewable-based energy systems, identifying the root sources of misalignments while taking into account the interactions with the wider socio-economic and Earth systems. **This holistic approach aligns the energy transition with wider socio-economic imperatives by putting in place organisational structures that are capable of providing affordable, reliable, renewable energy to all, with the required climate ambition, while helping to reduce inequalities, equitably share benefits and burdens, and build the needed socio-economic resilience to navigate the climate impacts that can no longer be avoided (*i.e.* a fair and just transition).** Such a systemic approach builds on improved governance (participation, transparency and accountability) that aligns decision making, institutions, agents and instruments (inside the power system and beyond) to make the transition goals a reality.

The dual procurement proposal is meant to be a starting point for discussion. Further work is needed to advance and refine these concepts, incorporating both country- and region-specific contexts. This report highlights the need to advance this transition dimension and to inform necessary discussions in an inclusive way.

PART 1

A HOLISTIC VISION OF POWER SYSTEM ORGANISATIONAL STRUCTURES IN A TRANSITION CONTEXT

1

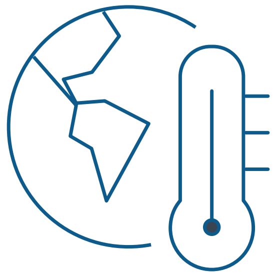
THE NEED AND URGENCY FOR THE ENERGY TRANSITION: ADDRESSING CLIMATE BREAKDOWN

Despite growing evidence of human-caused climate change, global emissions of carbon dioxide (CO_2) have continued to grow, increasing 1.5% annually on average during the last decade (Global Carbon Project, 2022). The gap between observed emissions and the reductions needed to meet internationally agreed climate objectives is widening (UNEP, 2020).

If left unchecked, those emissions could contribute as much as 4-5 degrees Celsius (°C) of planetary warming on average by 2100, causing significant damage to the environment and to socio-economic systems, with consequences for the human populations that depend on them.

The year 2020 was one of the warmest on record, and the effects of climate change have become increasingly apparent, with wildfires, droughts, storms and glacial melting intensifying (IPCC 2018, 2014; UNEP, 2020).

The organisational structures upon which our socio-economic system operates may be key enablers of or fundamental barriers to the needed transition.



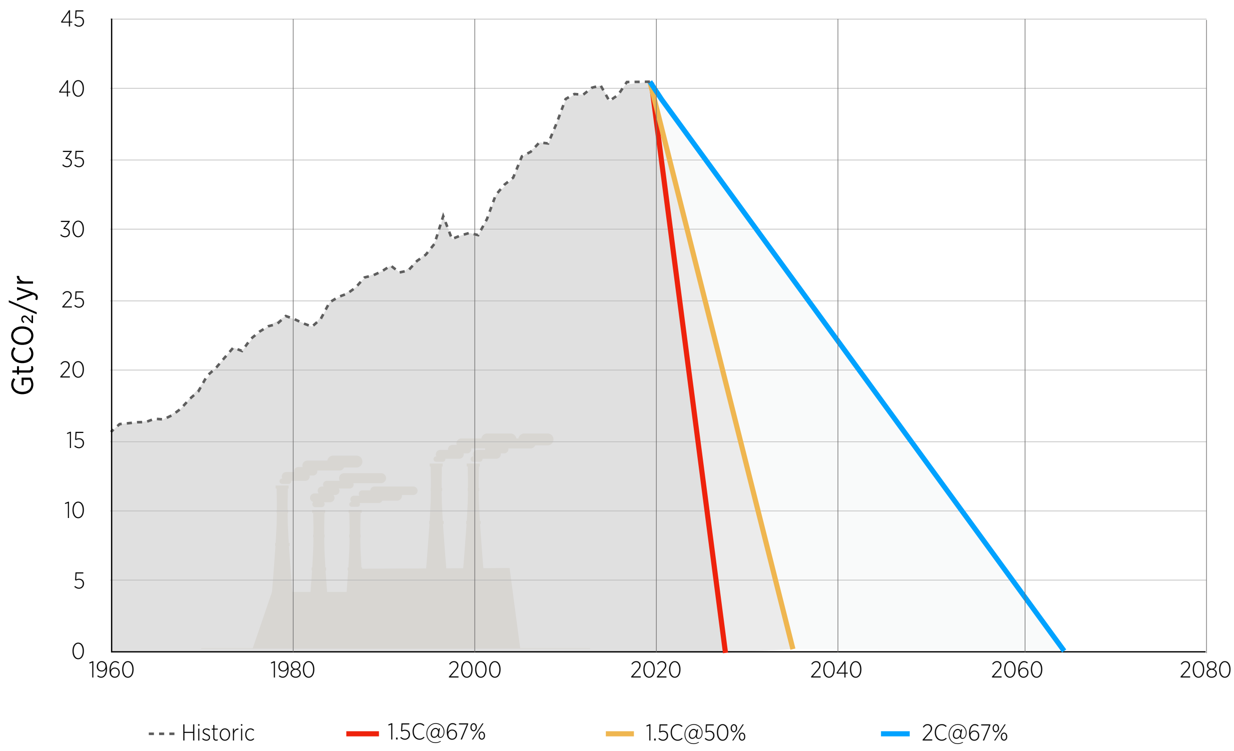
Recognising the urgent nature of the crisis and taking action to ambitiously mitigate greenhouse gas emissions would reduce the scale of the adverse effects, better securing the well-being of our planet and the prosperity of its inhabitants. Meanwhile, delays in undertaking effective mitigation action greatly increase the challenges of transition. If effective mitigation efforts had started by 2000, stabilising global warming at 1.5°C would have required average mitigation rates of around 4% per year, whereas starting these efforts by 2019 would have required average mitigation rates of around 19% per year[6] (UIO, 2020).

Another way to grasp the urgency of the required transition is by considering linear mitigation pathways that are compliant with the available carbon budgets. As shown in Figure 1, a linear mitigation pathway starting in 2020 would have to be completed by 2026 to comply with the carbon budget compatible with 1.5°C warming at 66% likelihood, by 2033 to comply with the budget for 1.5°C at 50% likelihood and by 2060 to comply with the budget for 2°C at 66% likelihood. This would mean annual reductions in CO_2 emissions of 7.1 gigatonnes (Gt), 3.2 Gt and 1.1 Gt, respectively (Le Quéré, 2020).

These emission reductions can be contextualised with the expected effects of COVID-19 on 2020 emissions. In the wake of the pandemic and consequent lockdowns, an estimated 8.8% less CO_2 was emitted in the first six months of 2020 than in the same period in 2019. In some individual countries, daily global CO_2 emissions reached peak reductions nearly four times higher (-26%) during the first half of 2020.

6 This is assuming the Intergovernmental Panel on Climate Change's (IPCC) SR1.5C carbon budgets (based on average surface air temperature and without including unaccounted Earth system feedbacks) and considering approximately exponential decay pathways that take into account the initial inertia associated with societal and infrastructural change, and hence have annual mitigation rates that gradually take off during the first years of the transition.

FIGURE 1. **Linear mitigation pathways for complying with the available carbon budgets**



Based on historic CO_2 emissions from Global Carbon Project (2022) and on carbon budgets from the Intergovernmental Panel on Climate Change's (IPCC) SR1.5C, based on surface air temperature, including IPCC estimates of Earth system feedbacks (IPCC, 2018) and factoring in the impact of 2019 updates on sea-surface temperature measurements (Hausfather, 2018).

Reducing carbon emissions in line with the requirements for avoiding climate breakdown is only conceivable if there is an unprecedented transition in all parts of society, including in energy, land use, urban life and infrastructure use; in the role of the industrial sector; and in the economy and governance (IPCC, 2018). Each of these essential pieces of the global transition calls for committed policy making and enhanced governance. In this tight transition context, paying attention to existing organisational structures to avoid additional barriers to transition (and associated delays) is paramount.

The transition in the energy sector (also known as the **"energy transition"**) is critical to limit climate breakdown, as the energy sector alone accounts for more than 70% of global greenhouse gas emissions (Climate Watch, 2020). All credible energy transition scenarios point in the same direction: the main ingredients of a successful energy transition are renewable energy and energy efficiency, in combination with electrification. However, these ingredients are still not prevalent in the global energy mix. Moreover, the energy sector is embedded within the economy and supplies its needs. Properly managing the evolution and structure of the economy is paramount to achieving the required decarbonisation rates.

The organisational structures upon which our socio-economic system operates may be key enablers of or fundamental barriers to the needed transition. Too often these organisational structures are taken for granted and do not receive enough attention when planning transition roadmaps. This report focuses on one key organisational structure: the power system. As the report shows, power systems are at the centre of the energy transition, and their organisational structures influence how and to what extent renewable energy technologies are deployed.

The analysis aims to set the scene for undertaking an informed discussion about the need and options to transition power system organisational structures, while keeping a holistic approach that recognises the embedded nature of power systems within energy, economic, social and Earth systems.

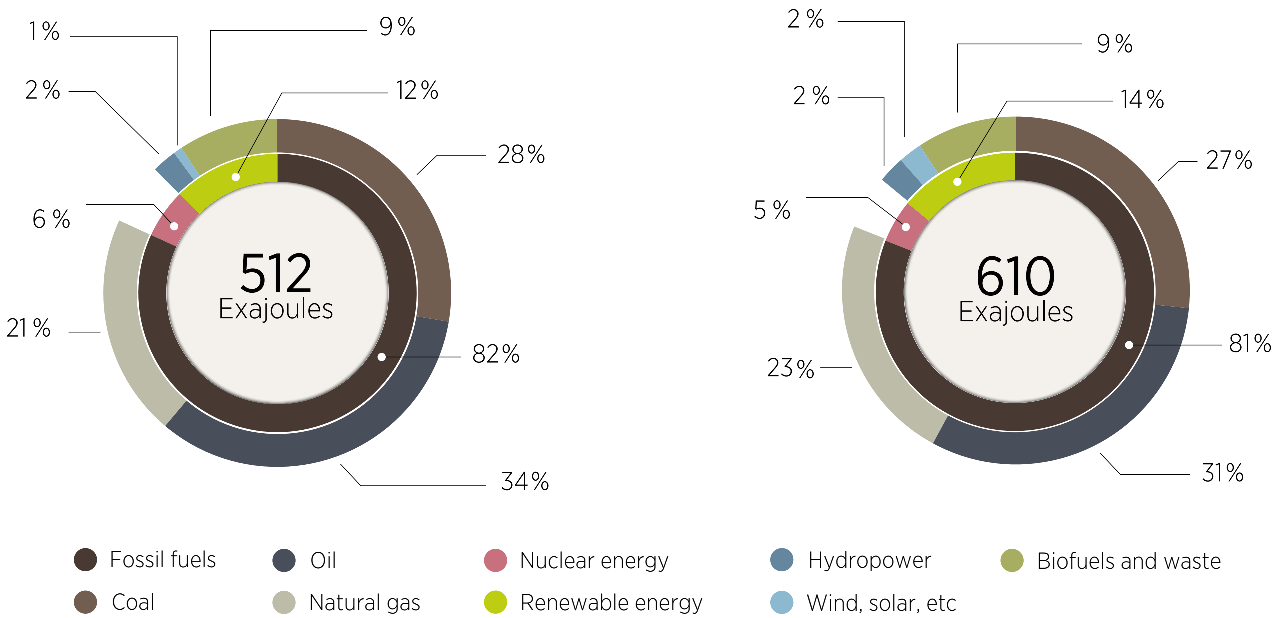
Following the introductory chapter, chapter 2 explores the implications of the energy transition for power systems. Chapter 3 presents the prevalent power system structures, and chapter 4 discusses the misalignments between these structures and the energy transition. Chapter 5 delves into the role of markets, and chapter 6 introduces the concept of "dual procurement" as a power system organisational structure that is fit for the energy transition.

1.1. THE NEED TO RESHAPE THE ENERGY MIX

In addition to deploying the potential for energy efficiency and addressing the structural socio-economic elements that drive increases in energy demand, successfully implementing the energy transition requires deeply reshaping the energy mix within short time frames. The power sector will play a prominent role in this, with electricity providing solutions to decarbonise a large share of energy end uses with renewables, and, consequently, the relative weight of the power sector in the energy system increasing.

Prior to the COVID-19 pandemic, energy supply and use were increasing substantially every year. The global total primary energy supply grew 18% between 2009 and 2019, to 606 exajoules (EJ). Fossil fuels (coal, oil and natural gas) accounted for 80.9% of the total in 2019 (down slightly from 81.6% in 2009), whereas renewable energy accounted for only 14.1% in 2019 (85.5 EJ) (Figure 2). However, this is up from a 12.6% share in 2009, showing the growing role of renewables. Nuclear energy provided the remainder of the global supply with 30.3 EJ in 2019.

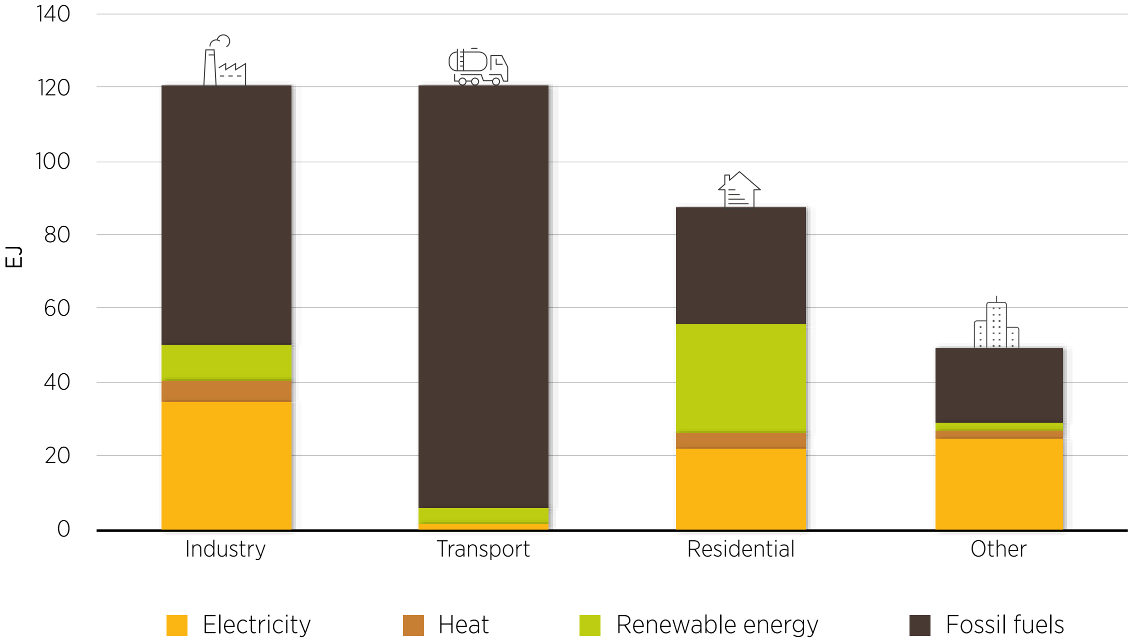
FIGURE 2. Global total primary energy supply, 2009 and 2019



Source: IEA, 2021a.

Energy is consumed in three main sectors: industry and transport, each accounting for 121 EJ of final energy consumption in 2019, and the residential sector (88 EJ). Other sectors (commercial, fishing, agriculture, etc.) together accounted for the remaining 60.5 EJ (Figure 3).

FIGURE 3. Final energy consumption by sector in 2019



Source: IEA, 2021a.

Renewable electricity is being deployed at a rapid rate (IEA, IRENA, WHO, UNSD and World Bank, 2020), as record-setting low costs drive the growth in renewable power generation technologies. Four-fifths of the solar photovoltaic (PV) and wind projects slated for commissioning in 2020 were expected to produce electricity cheaper than any fossil fuel alternative (IRENA, 2020a). Electricity currently accounts for between 3% and 33% of final energy consumption, depending on the sector. The accelerated electrification of end uses provides a key pathway to advance the energy transition, in addition to offering important efficiency benefits. Electrified end uses can also become sources of flexibility for the power sector.

Renewable electricity as a transition enabler

As renewable electricity generation becomes cheaper and scalable, the electrification of end uses (both direct and indirect[7]) becomes a cost-effective and environmentally friendly solution to provide energy services – while simultaneously offering an opportunity to increase the rate of energy transition. The electrification of end uses and the substitution of other energy sources and carriers with electricity is usually referred to as "sector coupling" (Figure 4).

[7] Indirect electrification refers to the use of electricity to produce another energy carrier, such as green hydrogen or e-fuels.

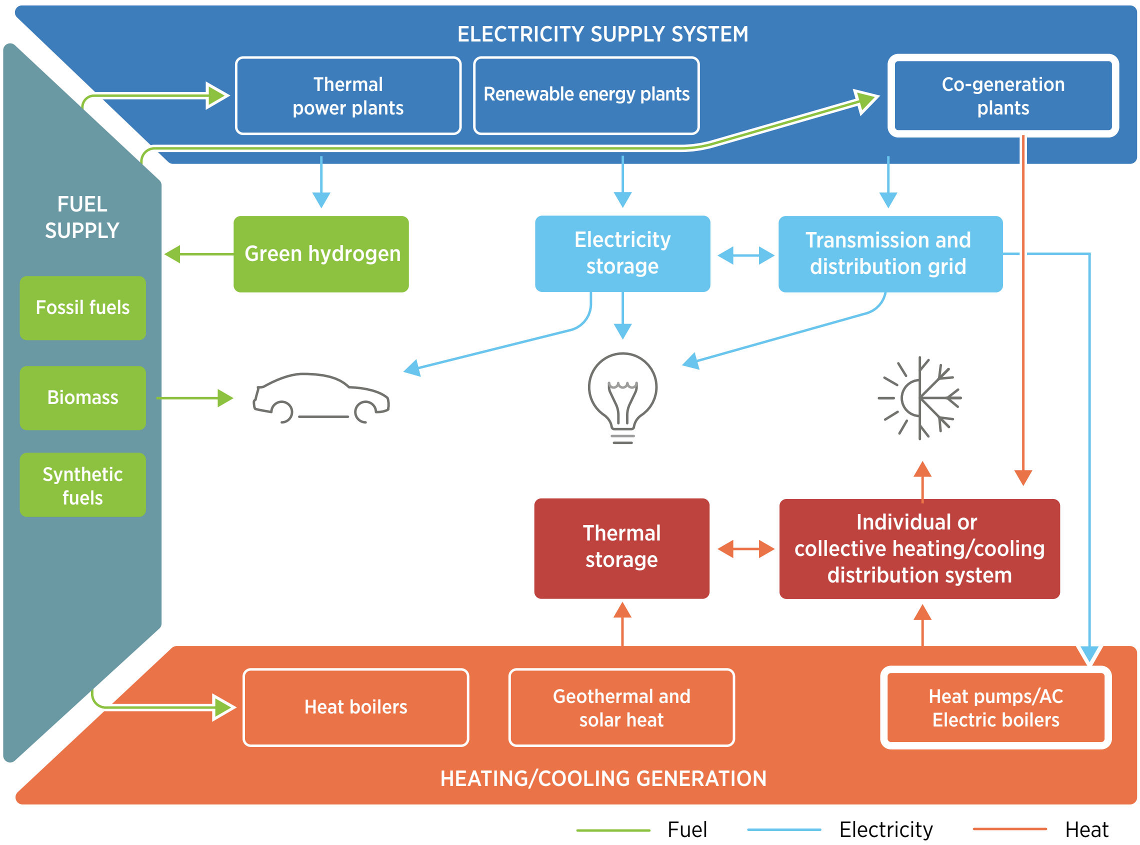
Sector coupling, in this context, involves two aspects of energy system planning and operation. First, an energy source is linked to a type of service (*e.g.* the electrification of heat and transport). Second, new links are created between energy carriers (*e.g.* electricity is used to create a synthetic fuel that can then be used to provide a service). This second type of coupling allows the indirect electrification of processes that cannot be electrified directly (*e.g.* industrial processes).

An energy transition based on renewables brings a huge increase in the scope for sector coupling, and could unlock high transition rates and flexibility resources (IRENA, 2020b; IRENA and SGCC, 2019; IRENA, IEA and REN21, 2018; IRENA Coalition for Action, 2019).

Electricity is a versatile energy carrier that can be used for almost all end uses and has the advantage of reducing air pollution compared to traditional combustion devices (*e.g.* stoves or cars). Combined with the low cost of renewable generation, renewable electricity represents a low-cost option to decarbonise the energy sector. At the same time, solar PV and wind generation (known as variable renewable energy, or VRE) is uncertain, depending on weather conditions. Having a high share of VRE in a power system poses increased system integration challenges. Sector coupling solutions help to mitigate these challenges by providing flexible electricity demand, which can follow generation patterns. This includes the use of active demand management, energy storage and green hydrogen.

Sector coupling with renewable electricity creates a virtuous cycle, where electrification drives new uses for VRE while facilitating its integration in the power system, which then decreases the costs of VRE generation and accelerates the switch to electricity for end uses. The solution of electrification using renewable electricity as the principal energy carrier across all demand sectors (transport, industry and buildings) is central to most energy transition scenarios.

FIGURE 4. **Sector coupling**



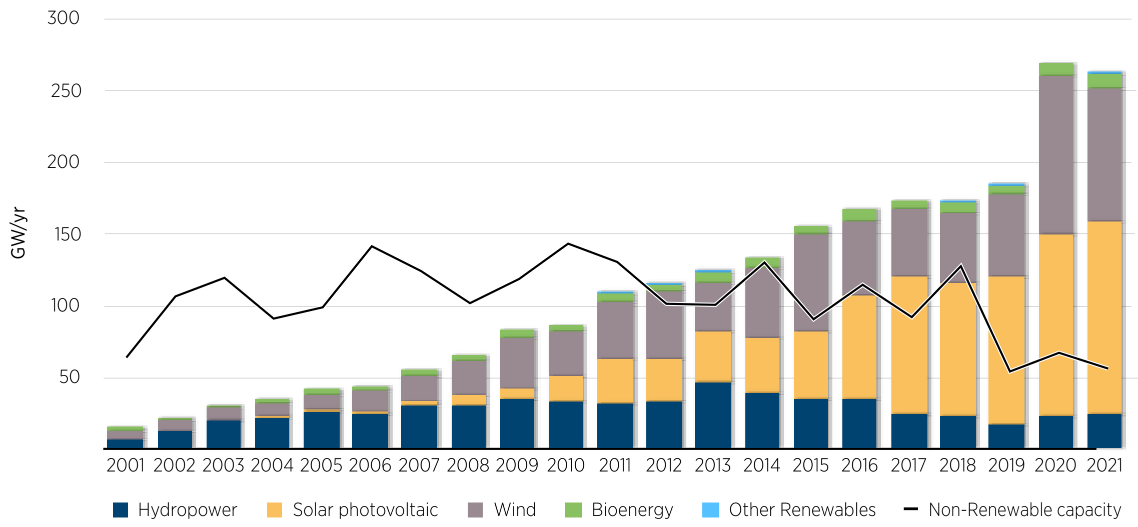
Source: IRENA, IEA and REN 21, 2018.

The recent evolution of the power sector and the challenges ahead

The power sector has been leading the energy transition, with the highest rates of renewables deployment across sectors. Appropriate support policies and reductions in technology costs have enabled this evolution.

Annual renewable energy deployment in the power sector increased around 11-fold during the nearly two decades between 2001 and 2019, rising from 16 gigawatts (GW) to 176 GW (Figure 5). Deployment was initially driven by hydropower, with wind taking the lead in around 2005 and solar PV in more recent years. By 2020, the total global renewable power capacity was 2 639 GW. The added capacity of renewables has surpassed that of conventional generation (fossil fuels and nuclear) every year since 2012, with the exception of 2014.

FIGURE 5. **Global net added power generation capacity, 2001 to 2021**



Source: IRENA, 2021a.

The significant growth in wind and solar PV capacity during the last decade has resulted in an increasing share of VRE. Whereas in 2001 VRE represented 43% of the added renewable capacity, in 2019 it represented 89%.

Despite these strong trends, both the current total installed capacity of renewables and annual deployment rates are lagging behind what is required for an energy transition that is consistent with global climate targets. In this context, it is paramount that policy makers foster the deployment of renewable energy in the power sector (and, thanks to sector coupling, in other end uses) by putting in place power system organisational structures that are fit for renewables and capable of enabling high transition rates.

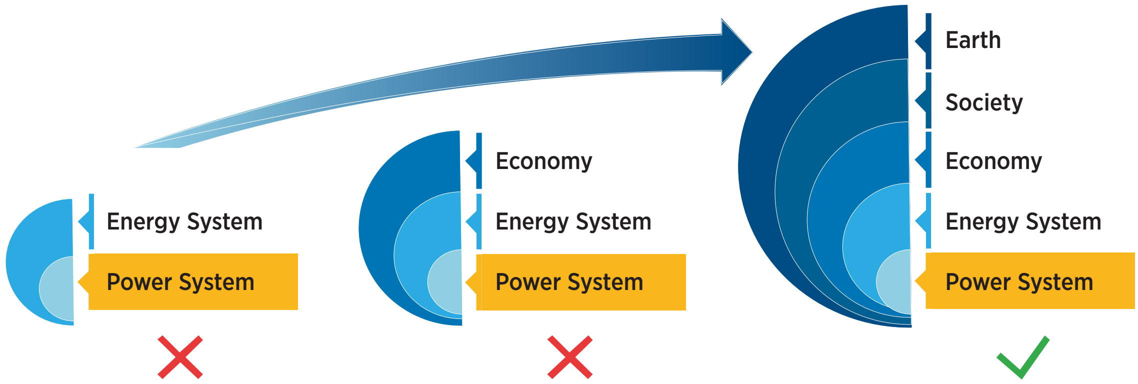
The power system organisational structures that are prevalent today were developed for the era of conventional electricity generation – *i.e.* for large, centralised, dispatchable and mostly fossil fuel-based generation with high variable costs. This calls for scrutiny of the existing power system rules, regulations and market structures, to update and reform them to the challenges of the renewable energy era.

The next section delves briefly into definitions of the power sector, its role in the broader picture and the main aspects of the sector that will be prevalent in planning and implementation of the energy transition.

1.2. THE POWER SYSTEM AND THE WIDER PICTURE

Energy is a catalyst and enabler of socio-economic prosperity. Community development requires reliable, adequate and affordable energy services. Electricity and other forms of energy help bring vital services to households, improving the quality of life and increasing the opportunities for education, health care, information and socialisation. Access to affordable energy allows industries to develop and thrive. The energy system is thus fully embedded in the economic system and is one of its enablers; the economy in turn is embedded in society and the Earth. Multiple links and feedbacks exist between these systems (Figure 6).

FIGURE 6. The embedded nature of power systems



The "power system" physically entails all components related to the production, conversion, delivery and use of electricity. It is embedded in the energy system, with multiple links and feedbacks with other components of the energy system. These links and feedbacks will likely become even more prominent as the transition progresses and as the energy system is further integrated through sector coupling.

The energy transition thus influences, and is influenced by, elements external to the boundaries of the energy and power systems. There is a need for a systemic approach and a holistic perspective to understand these systemic interactions. The energy transition must harness all the potential and synergies of these interactions.

Power systems will play a pivotal role in the energy transition. Failure to exploit the synergies between the power sector and the broader energy sector, economy and society will result not only in a lost opportunity to maximise the benefits of the energy transition, but also in barriers to its full achievement.

Bringing everyone on board to underpin the deep transformations needed for a successful energy transition requires properly addressing dimensions of justice and fairness.

However, the technologies related to the energy transition differ greatly from those on which the current power systems were based. The stakeholders involved in defining and operating the power system will also likely evolve during the transition. Hence the organisational structures of power systems need to be rethought in order to align them with the characteristics of renewable-based energy systems. The energy transition also needs to address other socio-economic challenges, such as energy access and energy poverty (Box 1), with power system organisational structures playing an important role.

Bringing everyone on board to underpin the deep transformations needed for a successful energy transition requires properly addressing dimensions of justice and fairness. It is thus essential to understand the historic evolution of power systems and how they need to further evolve to align with the needs of the energy transition and people's needs.

Power system organisational structures must address access and affordability challenges as an integral part of their social value scope and to prevent transition barriers.

Box 1. Energy access and affordability

Modern energy services play a crucial role in any society, bringing light, warmth and means of communication and information to households, as well as supporting social services and economic activity.* Still, a large part of the world's population does not have full access to energy services.

While some regions are engaging in the electrification of heating and transport, with digitalisation playing a growing role, an estimated 756 million people (around 10% of the world's population) did not have access to electricity services in 2019, even though nearly 1 billion people gained electricity access between 2010 and 2019.

Dramatic cost reductions have made renewable technologies the most economical and reliable option for off-grid electrification. This makes it possible to leapfrog the need for stand-alone fossil fuel solutions, while increasing the affordability of off-grid electrification. If properly planned and managed, this also opens the opportunity to sustainably evolve from stand-alone systems to minigrids, which can become a functional part of national power systems once they are grid connected.

The energy access challenge goes beyond electricity access. Worldwide, an estimated 2.8 billion people still depend on traditional biomass for basic energy needs such as cooking and heating. And even many households that are connected to electricity infrastructure remain unable to afford the full array of modern energy services, which has long-term effects on the well-being of occupants. Energy poverty may cause people to fall below the poverty line, instead of being an effect of poverty, in particular when energy costs increase to notable levels and impact a household's socio-economic development.**

Energy poverty and vulnerability are common across countries despite different power system organisational structures. Moreover, some of the trends that could unfold alongside the energy transition, such as evolving pricing mechanisms and lower social protections, may cause a resurgence of energy poverty in certain areas as energy-vulnerable populations cross the energy poverty line. For example, in Southeast Europe, there is a growing wariness about the risk that power market liberalisation and the costs of renewable energy deployment schemes may increase energy prices to unsustainable levels for energy-vulnerable households.

* IRENA's energy transition welfare index has one of its five dimensions dedicated to evaluating energy access progression, including both basic energy access and progression along the energy access ladder.

** During the discussion of the 2050 Energy Roadmap, the European Commission stated: "energy poverty is one of the sources of poverty in Europe".

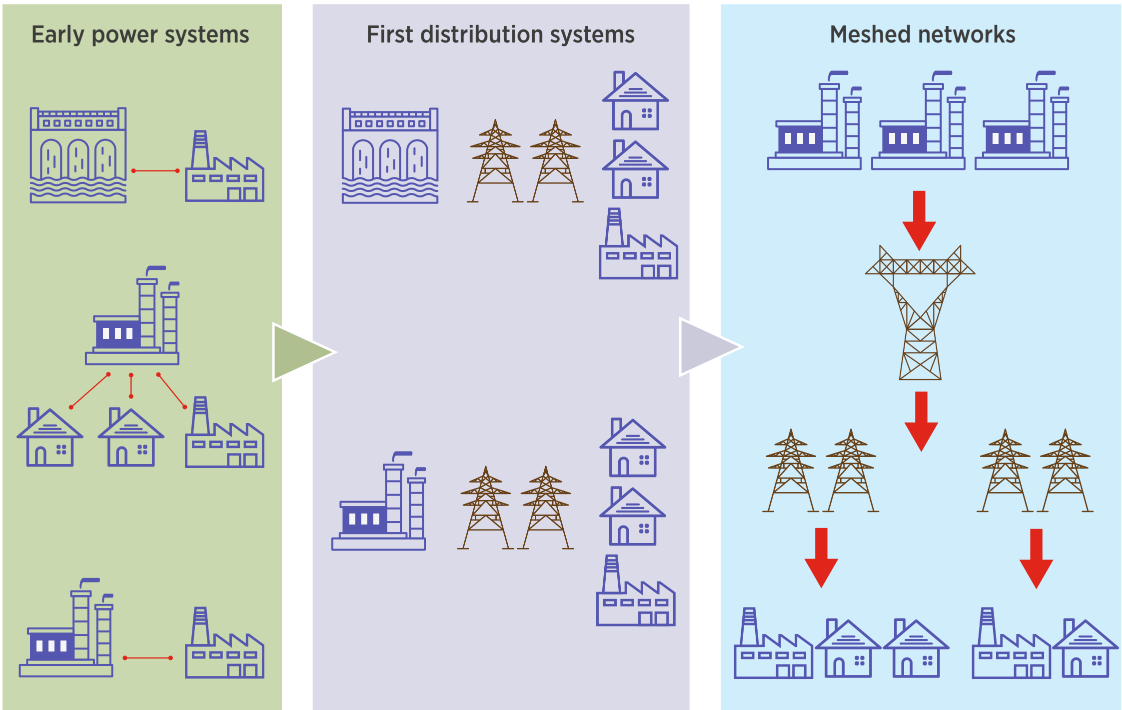
Source: IRENA, 2019a.

1.3. POWER SYSTEM ORGANISATIONAL STRUCTURES

When power systems were first developed, electricity was produced close to the point of demand, which was typically an industrial load. As cities were electrified, distribution grids and later transmission grids connected the urban centres with relatively distant power generators. Gradually, meshed networks with multiple generators providing electricity to various loads were developed, leading to the first national grids (Figure 7).

As physical power systems evolved, the way that electricity was procured and allocated changed. Whereas at the onset **bilateral agreements** between the producer and the user were the norm, the advent of grids connecting multiple generators to multiple users made more complex **power system organisational structures** necessary.

FIGURE 7. Elements and evolution of the power system



Current power system organisational structures are differentiated in multiple ways, due mainly to the context-specific historical evolution, maturity and predominance of market or regulatory paradigms. An important differentiating element is the degree of competition within the organisational structure. Whereas at the beginning of the 20th century **vertically integrated regulated monopolies** were commonplace, since the 1980s various elements of competition have been introduced worldwide. These range from fully unbundled and liberalised systems in both the **wholesale** and **retail operations** to **power purchase agreements** between a regulated utility and private companies.

The expectation was that competition would increase the efficiency and efficacy of relatively simpler power systems than today, characterised by centralised, dispatchable generation with low technological diversity and passive demand (Batlle, Rodilla and Mastropietro, 2021). However, the adoption of competition in power systems has not been applied in a uniform way worldwide, reflecting differences in national backgrounds and political objectives. Similarly, regulated systems differ in their regulation, goals and ownership structures. For example, even in the case of monopoly, the utility can be state-owned, with a ministry in charge of its operations, or privately owned and heavily regulated (as in Japan).

One misconception regarding the liberalisation of the power system structure stems from the idea that liberalisation is a one-way process. Instead, many factors influence the process, including evolving technological, political, social and environmental contexts; constant renegotiations by the parties involved; experiences; failures (environmental impact and other externalities, risk aversion, information asymmetries, etc.); and objectives. Many power systems have taken steps back in the liberalisation process, to ensure system adequacy and reliability and to address specific energy transition challenges that could not be provided by the liberalised systems (Batlle, Rodilla and Mastropietro, 2021). This was the case in Brazil and other Latin American countries (IRENA, 2016a), as well as in Europe with the introduction of capacity mechanisms. Hence the organisational structure of the power system may change in response to system needs and political objectives.

The urgent socio-political imperative of decarbonising the power system introduces strong high-level constraints and entails new disruptive technologies, with an overall change in the way electricity is generated, distributed and consumed; altogether this increases systemic diversity and complexity. So far, the deployment of new technologies, in particular renewable energy power plants, has been driven by pro-active policy making (regulation) that provided dedicated support mechanisms. This support was originally aimed at helping technologies progress along learning curves.

However, policy support now plays the main function of addressing the inability of current organisational structures to deal adequately with the characteristics of these technologies. Power system organisational structures need to evolve to support the energy transition. Delays in addressing the re-designs of organisational structures will cause barriers that will ultimately hinder or hamper the extent of the energy transition. The effect of the interaction between support mechanisms and prevalent power system structures is described in the next section and in more detail in chapter 4.

One misconception regarding the liberalisation of the power system structure stems from the idea that liberalisation is a one-way process. Instead, many factors influence the process, including evolving technological, political, social and environmental contexts.

1.4. MISALIGNMENTS DURING THE TRANSITION

Advancing the energy transition under current power system organisational structures has required implementing additional long-term mechanisms for the procurement of renewable electricity generation. Successful deployment instruments have mainly taken the form of **feed-in tariffs, feed-in premiums, green certificates, auctions and dedicated power purchase agreements**. Currently the chief procurement mechanism is through competitive long-term contracts (auctions and tenders). These have proved to function well for price discovery and reduction, to the point that they are now widely used to achieve other technical and socio-economic objectives, beyond simple cost compression (IRENA, 2019b).

These instruments were conceived primarily as financial instruments to lower the risk of investment in renewable electricity generation assets. Early on, the risk mitigation addressed mainly the high costs and uncertainties from technologies in the initial stages of their learning curves. These mechanisms have successfully fostered the deployment of high shares of renewable energy technologies (solar PV and wind in particular) in many countries where they were marginal only a few years ago.

Renewable energy technologies have matured, with decreasing costs (IRENA, 2020a) and increased investor confidence. However, even in developed markets, merchant investments still struggle to be deployed at the necessary scale and pace to meet the emission reduction targets set under the Paris Agreement on climate change.

In some regions of the world, this slow pace of deployment is still due in part to immature structures and high risks. However, it is increasingly clear that some power system structures are struggling to support the deployment of large shares of renewable energy. This is not unexpected: these structures were designed for the fossil fuel era[8] and therefore were optimised to deal with the characteristics of centralised, dispatchable, mostly fossil fuel (with high operation costs) plants within a much simpler techno-social context.

The increasing deployment of renewables may have a direct impact on power systems by, for example, lowering the average price of wholesale markets and increasing grid costs. This report assesses the dynamics behind these aspects under the lens of "misalignments". Misalignments may have the effect of halting or slowing the energy transition (see "In Focus" section). In a few cases where misalignments have become evident, energy authorities, regulators or policy makers have found solutions to temporarily address them.

It is crucial to understand the real causes of misalignments, which often may reside in the very design of the power system structure. This report delves into all these aspects and proposes a way forward to overcome challenges and successfully advance the energy transition.

[8] "Fossil fuel era" refers to the period from the inception of power systems to the energy transition. It is characterised by the presence of large centralised power plants. These include nuclear, hydropower and fossil fuel plants, which have represented been the dominant technologiesy in most power systems.

2 THE TRANSITION'S IMPLICATIONS FOR THE POWER SYSTEM

For the energy transition to contribute to addressing climate change and sustainability challenges, a holistic approach that pays attention to all layers of the system and their interactions is needed. This chapter describes the context in which the energy transition will unfold, highlighting cross-cutting systemic dimensions, and different elements and dynamics at play.

Power system organisational structures are themselves the product of the transformative processes that the wider energy and socio-economic systems have been undergoing, and of their interaction with the power system. Now, due to the urgency of facing the climate emergency, organisational structures will need to anticipate and not only adapt to the future paradigm shifts transforming societies and the Earth, so that they can help facilitate the transition.

2.1. THE CROSS-CUTTING DIMENSIONS

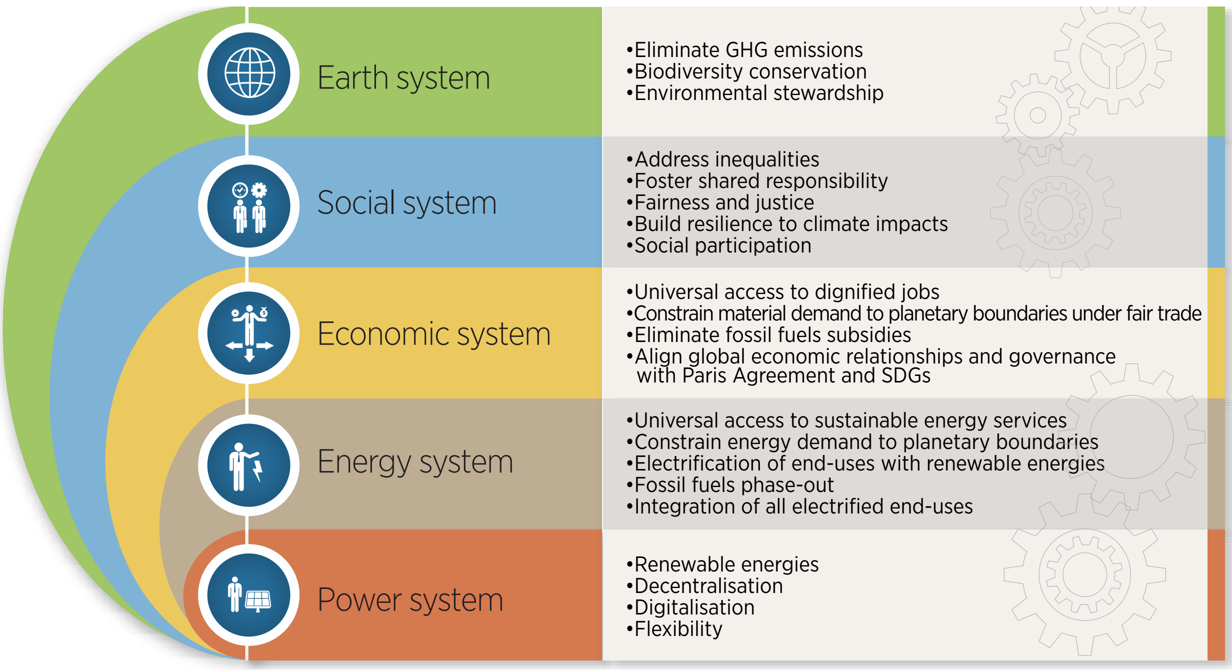
Today's prevalent organisational structures have not been reflecting most of the effects of power generation, transport and use on the wider socio-economic and environmental systems. For instance, they have allowed users to waste energy, or generators to choose polluting generation technologies. But the energy transition does not exist as a stand-alone process. Figure 8 summarises the desirable cross-cutting transformations that the energy, social, economic and Earth systems would need to undergo

Power system organisational structures are the product of the transformative processes that the wider energy and socio-economic systems have been undergoing, and of their interaction with the power system.

at the same time as delivering the energy transition, if it is to be a just and resilient transformation. If power system structures continue to be blind to wider systemic interactions, then barriers threatening to derail the energy transition could arise (see chapter 4).

This is especially relevant given that the current energy transition is not driven just by techno-economic considerations, as was the case when the world moved to fossil fuels. For the current transition, a fundamental driver is the looming climate crisis and its socio-economic impacts. The tiny carbon budgets that remain to prevent global warming beyond 1.5°C to 2°C (see chapter 1) require a rapid transition in a world that has limited remaining resilience (because of extreme biodiversity degradation and profound social inequalities and exclusion).

FIGURE 8. Cross-cutting transformations for a fair and just energy transition from the power, energy, social, economic and Earth systems



Note: GHG = greenhouse gas; SDGs = Sustainable Development Goals.

Rapid transition rates always entail socio-economic stress, especially around the (unequal) share of benefits and burdens of the transformation. Communities that are already impoverished and living in degraded ecosystems present limited resilience to further economic and ecological stress that could be locally induced by the transition, although the overall impact is expected to be positive in the long run. If not addressed, pre-existing inequalities increase the risk of social opposition to the transition or social polarisation around the transition trade-offs (NGFS, 2021). In this context, ignoring systemic interactions is not an option.

A holistic approach to the energy transition can support societies to face the climate crisis while simultaneously creating better opportunities for widespread prosperity (IRENA 2020b; 2021b). Articulating such an approach requires gaining insights about systemic interactions and developing organisational structures that address them.

Social participation

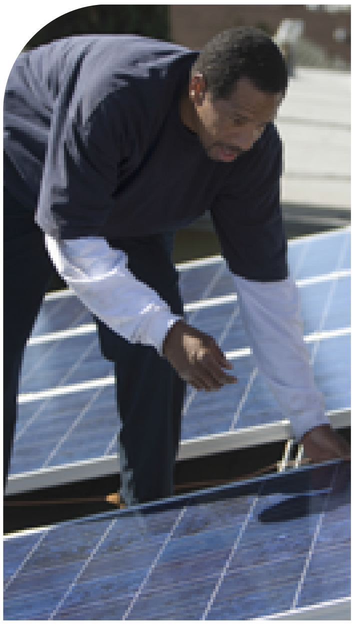
With the energy transition taking place alongside the unfolding of the climate and biodiversity crises, societies will require renewed, improved and adapted governance to steer the process, managing uncertainty and risks. Hence it is crucial to engage communities as active change agents rather than considering them just as passive consumers (O'Brien, 2018). Social participation will be key to ensure that the energy transition aligns with shared prosperity goals, thereby maximising its social value. Social participation in decision making is essential so that communities have a say in their energy future, especially when decisions on trade-offs are to be taken and the transition benefits and burdens have to be distributed.

Moreover, the increasing share of distributed energy resources (both generation and flexibility) brings the potential for the energy transition to facilitate social participation and improved governance. Materialising this potential, however, requires appropriate organisational structures and enabling policy frameworks that, themselves, are the product of participation and governance.

For example, regarding the contribution of citizens to system flexibility through demand response, it is essential that demand management will not be applied in an invasive or misinformed way, altering living conditions or exposing users to excessive quantity and price risks. Another example is energy communities, a tool for social participation in renewable energy and energy services projects that has recently been introduced in European Union (EU) legislation. Organisational structures have been prevalently designed for incumbents, and many Member States are still experimenting with how to correctly design them to be fit for energy communities' participation. Auctions design is one example (IRENA, 2019b).

Socio-economic system challenges

The energy transition also must interact with the prevalent economic set-up, which is based on globalisation and the extraction of increasing amounts of natural resources to feed unprecedented levels of consumption. In the last 50 years, the global economy has grown four-fold and international trade nearly 10 times (IPBES, 2019), which has led to a sharp increase in demand for both energy and materials, as well as to greater dependence of regional and local economies on international exchanges.




Workers installing solar panels, Shutterstock

Economic dynamics based on growth and resource extraction are putting rising burdens on societies and the ecosystems on which they depend, outpacing efficiency efforts to reduce energy use, material demand and waste generation. Increasingly, globalised socio-economic systems introduce an international dimension to the energy transition, requiring concerted action beyond national borders. Global socio-economic initiatives are struggling to take off with the needed urgency and depth. Global governance improvements are needed to align economic governance with climate and sustainability goals.

Organisational structures for sustainable energy systems will have to address the challenges from this inherited context. One example are international trade agreements that will need to be aligned with the need to decarbonise the global economy and SDGs.

Fossil fuel stranded assets

To comply with the goal of avoiding high socio-economic impacts from climate change, a big share of today’s existing and planned fossil fuel assets will need to be stranded during the energy transition[9] – *i.e.* phased out before completing their useful economic life. This may affect a wide range of fossil fuel assets, from the infrastructure needed for extraction and processing, to the infrastructure used for energy transformation (such as power plants), all the way down to internal combustion engine vehicles and the infrastructure required for their manufacture and maintenance. Although estimates vary widely, IRENA (2020b) assessed the value of assets at risk of stranding to be between USD 11.8 trillion and USD 19.5 trillion by 2050, depending on the pace of the transition. Hence the socio-economic impacts from this stranding process can be extensive, and the political economy complex.

The phasing out of fossil fuel assets will be entangled with the deployment of the infrastructure needed for a renewable-based energy system. This is already introducing powerful dynamics that, unless properly addressed by organisational structures, can introduce significant barriers to the transition. A case in point for the power sector is capacity markets and contractual mechanisms that entrench dispatchable fossil

[9] The objectives of the Paris Agreement imply that nearly all proven fossil fuel reserves and associated investments will become stranded resources (Bos and Gupta, 2019; Gupta and Arts, 2018; Rozenberg, Vogt-Schilb and Hallegatte, 2014; Wasserman and Cramer, 2016) and that any further delay implies an increase in stranded assets.

fuel generation and prevent the development and deployment of flexibility elements that are suited for a renewables-based power system (see chapter 4 for more on this and other related misalignments).

Stranding fossil fuel assets is likely to have deep socio-economic consequences, such as those resulting from the decisions of who will be bearing the burden of the associated economic losses. If the burden is placed on private investors that expected a return on their fossil fuel-related investments, strong resistance to the transition may be expected. If the burden is socialised, government fiscal budgets will be reduced and fewer resources will be available[10] to support the transition and to address its potential regressive impacts, which could also trigger barriers to transition.

For countries in the Global South, stranded fossil fuel assets have further ramifications. Countries that currently produce fossil fuels in these regions are often in the high end of the cost-supply curve and hence will be the first hit by a reduction in demand. Other Global South countries have recently discovered domestic fossil fuel resources and have expectations to become wealthy economies by exploiting them (Menas Associates, 2017). However, investing in these resources would intensify climate change (to which these countries are especially vulnerable) and slow the transition in these countries by locking in obsolete infrastructure. In the near future, this would produce stranded assets that will cost taxpayers money and limit the capability of countries to address socio-economic development needs. The issue of choosing a different development path away from fossil fuels has short-term economic implications for these countries, thus raising the question of the role that increased international collaboration, including international financial compensation, can play (IRENA and AfDB, 2022).

Earth system limits

Finally, all the power, energy, economic and social systems are embedded in the Earth system, which sets the physical limits that no other system can trespass. Past and current failures in making decisions according to environmental limits are at the root of today's climate and biodiversity crises. Thus, correcting this blindness to Earth system limits is fundamental for a successful energy transition, which is occurring on a planet that is already under severe stress caused by climate change, air and water pollution, soil depletion, massive biodiversity loss and natural resource overconsumption. Humanity has crossed several planetary boundaries (including related to climate change), increasing the risk of generating large-scale abrupt or irreversible environmental changes (Steffen *et al.*, 2015; Steffen, W. *et al.*, 2018).

Already, 75% of the Earth's land surface, 66% of its oceans and more than 85% of its wetlands area have experienced deep transformations. This is negatively impacting the well-being of at least 3.2 billion people, pushing the planet towards a sixth mass species extinction and costing more than 10% of the annual global gross domestic product (GDP) in the loss of biodiversity and ecosystem services[11] (IPBES 2018; 2019). This undermines socio-economic resilience for adapting to a fast-changing climate and reduces nature's capacity to absorb CO_2 (IPBES and IPCC, 2021; IPCC, 2018). The energy system has contributed greatly to this degradation through air, water and soil pollution; greenhouse gas emissions; deforestation; and habitat destruction from fossil fuel exploitation.

[10] This is especially true for monetary non-sovereign countries or countries with a strong dependence on foreign currency. Monetary sovereign countries issuing their own currency could in principle increase the deficit as needed by printing money (as long as the right policies are in place to control inflation), as indicated by Modern Monetary Theory, but inherited policy frameworks still introduce strong limitations to increasing deficits.

[11] Ecosystem services are defined as the benefits to humans provided by healthy ecosystems, such as natural pollination of crops, clean air, extreme weather mitigation, human mental and physical well-being, pathogens containment, etc.

Because the window of opportunity to stabilise the global temperature to safe levels is closing quickly, the energy transition must be deployed rapidly, as the consequences of no action would be catastrophic. Proposing progressive (linear) changes in the current socio-economic system is no longer sufficient to achieve the required emission reductions. The needed step changes require an effective re-organisation of national and international governance to be more effective in addressing the global socio-environmental challenges (Biermann *et al.*, 2012; O'Brien, 2018; Rockström *et al.*, 2017; Steffen, W. *et al.*, 2018).

Even under the most ambitious scenarios of mitigation, severe impacts on ecosystems (and the societies that depend on them) are expected to unfold. Building resilience – the capacity to adapt and recover quickly from impacts – emerges as a fundamental element of a transition strategy. When the interlinkages with the Earth system are properly addressed, the energy transition can help to reduce pressure on ecosystems by cutting emissions of greenhouse gases and other pollutants while providing the conditions for a shared prosperity. **This means in particular realigning private and public incentives with these goals**. Energy systems can also relieve their direct effect on biodiversity when designed to prioritise energy efficiency and material savings and to minimise environmental impacts.

Recognising the feedback loops between all the systems at play unveils the need to prevent unsustainable technological pathways in the name of decarbonisation. This is the case, for instance, of nuclear power, where the lack of appropriate waste management, accident records, insufficient civil liability, extremely long development times and lack of social control make it an inappropriate solution, even though it does not produce CO_2 in its generation phase. Intrusive geoengineering fixes are another case in point (Mycle Schneider Consulting, 2019).

A wide variety of transition pathways

A wide variety of pathways are available to a renewables-based energy system. The technology mix and transition speed can be adjusted to address different realities, including costs, technical limits, resource availability, etc. Ultimately, it will be the interactions among the different stakeholders, reflecting their interests and the diverse policies put in place to shape the transition, that will determine the outcome (Figure 8).

Focusing the energy transition narrowly on power systems may constrain its breadth and the speed of deployment by keeping important cross-cutting dimensions unattended. Organisational structures that are unable to capture the complete picture of the transition would risk projecting into the future the misalignments (chapter 4) inherited from the past.

Social, economic, energy and power systems will have to jointly serve the objective to keep the Earth a habitable planet, providing the conditions for a thriving society with a shared prosperity (Biermann *et al.*, 2012; O'Brien, 2018; Rockström *et al.*, 2017; Steffen, W. *et al.*, 2018). Power system organisational structures must serve this vision. Cross-cutting dimensions were already at play in these structures in the past, but now, under the climate urgency and resilience requirement, properly addressing them is an imperative.

Power system organisational structures, consequently, must adequately procure and distribute electricity to end users through the best options to reduce greenhouse gas emissions in the shortest possible time, contributing to halting biodiversity loss and fostering climate justice and shared prosperity.

2.2. KEY ELEMENTS OF THE ENERGY TRANSITION

As the energy transition unfolds, changes are expected in different dimensions, with significant implications for the power system. The next sections explore deeper insights on key changes induced by or happening in parallel with the energy transition, discussing their implications for the power system organisational structures of the future.

Renewable energy technology deployment

Renewable energy sources, together with energy efficiency and increased electrification, are the key options for decarbonising the energy system.

Although dispatchable renewable energy technologies – such as concentrating solar thermal power (CSP), geothermal, hydropower with reservoirs and sustainable bioenergy – are available, these contribute only a small share of planned capacity deployment. By contrast, variable renewable energy sources – specifically wind and solar – are the default options for new capacity at a global scale, thanks to the rapid reduction in their costs, challenging the prevalent power system structures. In 2020, VRE accounted for 91.3% of the renewable energy installed capacity added worldwide (Figure 5).

VRE power plants have very specific characteristics that make them different from other electricity-generating technologies:

- VRE exhibits **variable** hourly, daily and seasonal generation patterns and may not always be available when needed. This variability calls for additional system flexibility: the ability of the system to match demand and generation at any time.
- VRE generation is **uncertain**: generation can be predicted based on weather forecasts, but, while forecasting is improving rapidly, a degree of uncertainty regarding the actual production tends to remain.
- VRE is **location-constrained** and may be concentrated in specific areas with higher resources. This can lead to hotspots, which may require additional infrastructure, as well as to potential conflicts for land use. Moreover, hotspots can increase system vulnerability to weather events.
- The modular nature of solar panels and wind turbines (and increasingly other renewable energy technologies) allows for a more **distributed generation**, being able to rapidly deploy at different capacity and financing scales, with different ownership structures (*e.g.* small co-operatives or owners instead of the traditionally large utilities) and at different geographical locations.
- VRE generators have **low operating costs**. When generation is remunerated based on the marginal cost of the most expensive active generator, VRE generation decreases wholesale market prices. Although this may appear as a positive development, it is not necessarily good news because it can introduce misalignments as the transition unfolds (see chapter 4).
- VRE generators are **non-synchronous** power technologies[12] – that is, they have a power electronic interface with the grid, rather than a rotating mass that is directly connected via an electro-mechanical link. Under certain circumstances, this may pose challenges to the maintenance of system stability, which traditionally relies on the "inertia" provided by synchronous generators. While this involves changes in the approach to short-term system regulation, synthetic inertia options are available to provide grid stability with non-synchronous VRE (RGI, 2020).

These characteristics have resulted in a fundamental change in the way electricity is generated and used and in how power systems are operated.

[12] However, other renewable energy technologies – such as hydropower, CSP, geothermal and biomass – are synchronous, with generation characteristics very similar to fossil fuel power plants in terms of the services they can provide to the grid.

Box 2. Systemic changes introduced by deployment of variable renewable energy

From baseload to flexible systems. More flexible and integrated power systems are needed to maximise the value of low marginal cost VRE and, at the same time, guarantee grid reliability. Under these conditions, baseload plants lose the value they brought in the past. Existing baseload generation plants, unable to operate in a flexible mode, become a barrier to wider penetration of VRE (IRENA, 2015). Making fossil fuel generators more flexible, as proposed by incumbents, may hinder the transition by blocking the deployment of flexibility compatible with a renewable-based power system. Power system structures need to procure carbon-neutral flexibility for the system: batteries, power-to-X, or demand-side management, for example.

From marginal costs to low operational cost technologies. Most renewable energy technologies are characterised by high investment costs (capital expenditures, CAPEX) and very low operational costs (operational expenditures, OPEX). At increasing shares of renewable power, electricity procurement mechanisms based on marginal prices prove to be unable to simultaneously support the large-scale deployment of renewable energy sources and reap their potential benefits in terms of costs, magnifying misalignments (see chapter 4).

From price-based to value-based procurement. There are insufficient price signals to bring about the phase-out of fossil fuels and the diversification of renewable energy technologies and plant locations at the needed pace. The scope of procurement mechanisms needs to be widened from minimising price to maximising system and social value. A value-driven electricity procurement system is needed to better capture the geographical and temporal value of VRE sources as well as the value from the technology and ownership diversity linked to it. Conceptual proposals in this line are introduced in chapter 4. A focus on value requires internalising the negative impacts of the power system activities on societies and the planet and sustainable practices of production in all economic sectors, aiming at delivering prosperity. Power system organisational structures, through their interaction with the socio-economic system, must play a role in fostering and supporting this shift.

Considering a strong penetration of VRE reveals how far current power system organisational structures are far from optimal to manage a renewable-based system. Box 2 summarises the most prominent changes induced by the deployment of VRE sources and its implications in terms of organisational structures.

Electricity demand, power system flexibility and electrification

Power sectors are called to integrate an increasing number of electrified loads during the transition, such as, for example, mobility or the cooling and heating sectors. That these new loads are already efficient and flexible when connected to the power system has implications for the scale and costs of the new integrated renewable-based system. The electrification of end-use sectors brings not only new demand to the power system that can be flexible, but also new actors that, in turn, can deliver services of carbon-neutral flexibility, such as demand-side management, energy storage, smart charging of electric vehicles and renewable power-to-X solutions (*i.e.* renewable power-to-heat and renewable power-to-hydrogen).

On the one hand, today, power system flexibility is ensured mainly by large dispatchable power plants, large interruptible loads or interconnections. The phase-out of fossil fuel plants during the energy transition changes the currently available flexibility pool, which in any case is inappropriate for a VRE-based power system. On the other hand, there is still much room to introduce greater efficiency in current uses of electricity, opening space for the new loads to be electrified and reducing overall energy demand.

Deploying energy efficiency in the power sector is an essential instrument for reducing overall final energy demand. Reducing demand, in turn, is beneficial to adapt the speed of the energy transition to climate urgency requirements and to reduce its impact on biodiversity and societies (see chapter 4).

However, in 2018 the world demanded 10 times more energy than it did in 1919, when the global population was one-quarter the size. Economic growth has outpaced all energy efficiency efforts made in recent decades. Because the main drivers of energy demand are in the socio-economic system, beyond the power sector, a collaboration between all the systems, and their governance and organisational structures, is essential to give the correct signals to constrain economic expansion and to favour efficient energy uses and the electrification of end-use sectors. Hence new system structures will need to be able to speak to the energy and socio-economic systems, beyond the power system, to support key paradigm changes, as described in Box 3.

Deploying energy efficiency in the power sector is an essential instrument for reducing overall final energy demand. Reducing demand, in turn, is beneficial to adapt the speed of the energy transition to climate urgency requirements and to reduce its impact on biodiversity and societies.

Box 3. Demand, system flexibility and electrification paradigm changes

From passive to active demand. Power systems were developed with a largely inflexible and passive demand in mind, whether industrial or residential. The concurrent evolutions of digitalisation (see below), VRE and other distributed energy resources lead to a shift where users and energy demand can take an active role in the power system. Demand-side management will be an important component in this new paradigm. To activate effective demand-side response, in either a centralised or distributed way, organisational structures will need an increased focus on demand and its diversity, providing clear signals and frameworks to unlock its potential (i.e. conducive pricing, tariffs and charges, adapted mechanisms for industrial and residential activation, procedures fit for the different flexibility options). Engaging users in this task will require transparent, participatory governance, where operation procedures are understandable to everyday people.

An integrated energy system. The progress in renewable power generation technologies brings opportunities to increase the use of renewable electricity as a vector to directly and indirectly decarbonise end-use sectors, where the penetration of renewables lags greatly. With direct electrification, electrified end-use technologies can then become sources of additional flexibility by adjusting their demand profile and making their storage capacity (electrical or thermal) available to the power system. With indirect electrification, renewable electricity is used to produce intermediate fuels (hydrogen, synthetic fuels) to be used in end-use sectors, which greatly increases system flexibility by using intermediate chemical storage as a buffer between demand and generation. Organisational structures will need to foster collaborative frameworks that unlock all the synergies that become available through system integration and sector coupling.

Aggregation is strength. In a renewable-based power system an important share of the flexibility resources is distributed, both spatially and in terms of ownership, which calls for users' involvement in power system planning and operation. Aggregators and the appropriate accompanying regulation facilitate harnessing this flexibility potential (IRENA, 2019c), but many regulatory environments and their organisational structures still do not fully recognise the role of aggregators and limit their participation in the procurement of energy and flexibility.

Harvesting the full potential of implicit demand response. Potentially every user, with the appropriate tariff or value-recognition mechanism, can shift demand in time and contribute to peak-shaving, scarcity management or shifting power demand to accommodate power system needs (*e.g.* avoiding curtailment). Time-of-use tariffs – in which the price of electricity varies to reflect the value of electricity for the whole system in different periods – when suitably designed, act as key enablers to incentivise users to adjust demand or injection of excess production of distributed energy resources to the grid when it is more valuable for the system. There are several options to design tariff structures. To facilitate effective social engagement, residential retail tariffs need to be thoughtfully designed, also incorporating distributional considerations, both to choose the best option and to accompany it with mitigation measures to avoid leaving anyone behind.

Rethinking current plans to avoid stranding assets. Power system organisational structures have to foster and support the deployment and operation of the appropriate sources of flexibility for a renewable-based integrated power system. This involves deploying new sources of sustainable flexibility while simultaneously phasing out fossil fuel-based sources of flexibility that could become barriers to transition. Preventing any additional investments in fossil fuel-based flexibility resources would minimise stranded assets and their associated socio-economic impact (Bos and Gupta, 2019). In turn, this would require global fiscal and financial instruments and an increase in development co-operation.

Efficiency and electrification. Electrification of final energy demand contributes to both energy efficiency improvement and system integration. Hence, two trends are to be found during the transition of power systems: decreasing overall energy demand linked to efficiency improvement and increasing electricity demand because of the higher direct and indirect electrification of end-use sectors. The need for high transition rates adds further elements to the dynamic evolution of electricity demand during the transition. Organisational structures that favor both energy efficiency and electrification need to be in place. But to make electrification a real alternative to fossil fuels, electricity prices cannot be much more expensive than the fossil fuels it is meant to replace.

From a product-based towards a service-based economy. Ultimately, energy is demanded to procure a specific service, not simply for the sake of consuming energy. Service-based approaches can leverage the transition by further reducing energy demand beyond efficiency gains. As an example, access to mobility services instead of individual ownership of cars can enhance the efficiency gains of switching from combustion engines to electric vehicles while simultaneously reducing material requirements and industry's energy demand (reduced manufacturing) and citizens' welfare (fewer cars on the roads). Trends towards a service-based economy introduce a more general question on the role of property rights as opposed to access to energy services.

Digitalisation

Digital technologies supported by the Internet of Things, artificial intelligence and big data analysis are introducing new applications in the power sector, changing the boundaries and dynamics of the system. They are helping to improve real-time visibility of the whole system operation (generation, demand, network use, distributed flexibility resources, planning and forecasting of VRE production) and enhancing the control of power systems, hence facilitating the integration of renewable generation and distributed flexibility. When properly used, these innovations also create the opportunity to design better services to improve system performance, to optimise renewable assets, to allow deeper energy savings and flexibility, and to boost governance and citizens' participation (IRENA, 2019c). Therefore, digitalisation is also potentially a "game changer" of the power system under the appropriate conditions. The changes it can introduce (Box 4) need appropriate organisational structures to reap its potential benefits.

Box 4. Digitalisation and the power system changes it can trigger

From one-eyed systems to full visibility. The access and use of digital data allow for full visibility of the electrical system, in contrast to analog systems. Visibility opens the door to accurate and real-time control of system status and performance so that it can be managed and used more efficiently (electrical networks, vehicles, storage, demand for energy or services, distributed resources, etc.). Enhanced monitoring and control capability open the door to efficient management and operation of power systems with higher complexity (distributed generation, flexibility and demand, high VRE penetration, increased number of actors, etc.), improving the predictability of their behaviour. It also helps regulators monitor and confirm the information provided by stakeholders regarding the regulated activities they carry out, increasing their capacity to implement and manage effective regulation and sufficient, fair tariffs.

Recognising the value of data. For all these opportunities to be realised, quality and (near) real-time data access is an essential pre-requisite. Addressing what is a proper use of these data and what are the associated economic and ethical trade-offs requires proper governance and addressing the issues of data ownership, value, privacy and security. Democratic and fair frameworks for the gathering and use of data are a key element for enabling stakeholders' trust which, in turn, is essential for reaping the potential benefits of digitalisation.

More active and price/tariff-responsive demand. Digitalisation is facilitating the collection of data necessary for a more accurate estimate of the value of services provided to the power system with better spatial and temporal granularity. This allows demand to be more and more responsive to power system needs, and to make it increasingly interesting for users to actively participate in their provision.

Distribution of generation and other services

One of the fundamentals for the success of an ambitious energy transition is broader engagement of societies to actively participate in shaping, governing, building, financing and operating the different elements of the energy system while aligning them with the climate and resilience imperative. Distribution of energy technologies is a key enabler in this respect, offering greater flexibility and opportunities for local companies, municipalities, communities and individuals to get involved.

Despite the greater complexity in operating distributed energy resources, they can provide cost-effective solutions to network congestions at both the distribution and transmission levels, helping to address the technical challenges that increased deployment of VRE and distributed generation and flexibility may cause. In an energy access context, distributed renewables often provide the quickest and cheapest way to bring electricity access to unserved populations.

Box 5. Distribution of generation and other services: Systemic implications

A level playing field for distributed and centralised energy resources. Both centralised and distributed solutions have differentiated roles and benefits for the energy transition; a balanced mix of both centralised and distributed options can bring social and environmental benefits while being affordable. Failing to create a level playing field for distributed and centralised energy resources would result in significant barriers to the transition, with unintended inefficiencies (for instance in terms of land, energy or material use) and costs (MIT, 2016).

Collaboration and coherence among all stakeholders. Co-ordinated and coherent actions are an essential ingredient to enable the transition. Distributed assets bring an increased complexity in system operation at all voltage levels. Enhanced collaboration and real-time communication among all stakeholders involved (VIUs, system operators, generators, transmission system operators, independent system operators, distributed system operators, aggregators, end users, market operators, etc.) would enable the needed efficiency and co-ordination in infrastructure and resource use. With the right collaboration, the system evolution can be steered towards an integrated power system where both distributed resources and grid assets play their role.

Distributed resources as a solution for grid reinforcement deferral. Non-wire alternatives to substantial investments in grid reinforcement emerge from innovative distributed resources operation. Turning flexibility resources into virtual power plants* or virtual power lines** through aggregation makes it possible to integrate large VRE shares at both the distribution and transmission levels, reducing the risk of congestion and thus reducing their impact on grid reinforcement (IRENA, 2019c).

In areas not served by electricity grids or where service is unreliable, distributed renewable energy technologies make it possible to improve energy access by providing clean and cost-effective options for mechanical power, electricity generation, heating, cooling and cooking, in both urban and rural areas. Distributed renewables already provide electricity to between 5% and 10% of the population in several developing countries (REN21, 2021). Grid reinforcement deferral would benefit from organisational structures responsible for the remuneration of distribution activities that are able to give the grid operator the incentive or mandate to make the most of DERs.

Quicker and deeper transition. Every private or public space can potentially contribute to the energy transition. Engaging citizens, companies and administrations in distributed renewable energy, energy efficiency and flexibility can contribute greatly to achieving higher transition rates. Taking into account space and savings availability, around 50% of EU citizens would be able to produce renewable electricity through self-consumption or energy communities, amounting to around 45% of electricity demand by 2050. Around 83% of them could provide distributed demand response and energy storage (CE Delft, 2016). These figures include residences, small and medium-sized enterprises, and public buildings or facilities.

* Distributed energy resources can be operated together, creating a sizeable capacity similar to that of a conventional generator. This aggregation can be called a "virtual power plant" (IRENA, 2019d).

** Virtual power lines consist of large-scale storage systems "connected to the grid at two key points: one on the supply side, storing surplus generation from renewables that could not be transmitted due to grid congestion; another on the demand side, charged whenever grid capacity allows and then discharged when needed" (IRENA, 2020c).

For the potential of distribution to emerge, new organisational structures have to recognise and address the implicit and explicit bias of current power systems conceived under a centralisation paradigm, hence recognising the system improvements that distribution may bring about (Box 5).

Evolution of the actor landscape: New, active and connected participants

Energy utilities, in recent decades, have been in charge of delivering energy to households, public services, businesses and industries, playing an important role in implementing the current energy system in both regulated and liberalised environments. As discussed in the previous sections, the characteristics of the new elements of the integrated renewables-based power system enable and, at the same time, require a more granular participation.

Before the energy transition started, the structure of power systems (centralised, generation-focused, mostly fossil fuel-based) determined the role of stakeholders and their interactions. In both regulated and liberalised systems, these were based on a centralised control of information, separated roles along the value chain (as detailed in chapter 3) and almost unilateral interactions with users restricted to a customer role. In prevalent pre-transition power systems, the dialogue about the power system has been conducted as an expert's conversation where large-scale stakeholders participate directly, and the regulator and policy makers are in charge of representing the interests of passive users and the public.

With the inception of the energy transition, new models that enable the empowerment of users are being explored by means of distributed, aggregated and peer-to-peer models of decision making, operation, finance and ownership of renewable energy and flexibility. Examples of models that can channel social activation in the energy transition include net billing schemes for residential self-consumption in the EU and community-led 100% renewable off-grid power systems in rural areas in many developing countries, such as Thailand and the Philippines (Kubli, Loock and Wüstenhagen, 2018; Marquardt and Delina, 2019).

Additionally, companies and entities that manage assets that could contribute to the transition (such as back-up storage systems, electric vehicle fleets, trains, information and communication technologies, industrial processes, etc.) are now exploring options to get more directly involved in the power sector through emerging business opportunities.

This will inevitably lead to the entry of new actors as well as to a deep transformation of the core business of traditional actors, affecting all kinds of current organisational structures. This trend is reinforced by increased activity "behind the meter",[13] pushing the limits between the power system and the private domain, with user energy decisions having increasing implications for the overall energy system.

The entry of new actors with different activities and objectives makes it increasingly essential to establish mechanisms to align them all with the ultimate goal of the energy transition: to ambitiously mitigate greenhouse gas emissions and create community resilience. Collaboration, intended as the ability to act collectively in the pursuit of a common goal, is one of the keys to trigger synergies and prevent barriers.

Hence in addition to expert processes and regulation and market-driven decision making, involving people and their communities actively in decision-making processes and ensuring that their voices are included adequately in the design of policies that affect their lives and livelihoods is an essential element in the unfolding energy transition, bringing public interest to the forefront. Therefore, a broader co-ordination to achieve more holistic, dynamic and ambitious organisational structures arises.

[13] The term "behind the meter" refers to energy resources, whether generation, storage or flexibility, that directly supply homes and buildings without passing by the electricity grid. The resources are located on the user's side of the electricity meter as opposed to anything that happens on the grid side, which is deemed to be in "front of the meter".

Solar panels on the roof of a local market, Cold Hubs

The entry of new actors challenges the pre-transition power system in multiple ways, both in liberalised and regulated set-ups. The increasingly distributed nature of power systems disrupts the "top-down" structure of traditional utilities and incumbents. "Pro-use" or peer-to-peer electricity exchange and the rise of renewable energy-based electrification will also shape how users interact with utilities.

During the inception of the energy transition, incumbents (utilities, unions, transmission and distribution system operators, decision makers, etc.) will need to adapt to a new technological and governance situation, aligning with the energy transition's ambition and resilience goals. They will share the stage with new actors that are defining their role in a changing environment where the rules are still largely dominated by incumbents, although regulators are working to translate expectations of agents' diversification into reality through adapting regulation.

During the definition of roles, new dynamics will arise between old and new actors of power systems, including possible conflicts when defining one's niche. Only some of the old and new actors and their relationships will survive post-transition, depending on their and policy makers' ability to adapt to the decentralised, integrated, participatory and renewable-based energy system. Those who will not adapt to the new system, nor collaborate in supporting the transformative process, will eventually either become barriers to the transition itself or lose relevance and disappear.

Depending on the governance and organisational structures adopted, different mixes of regulation, participation and collaboration among actors will be put in place, with implications for both the stakeholder landscape and the configuration of the new energy system.

Hence power system structures will need to support the greater diversity of actors that the energy transition brings about and the paradigm shifts that this introduces (Box 6).

Power system organisational structures, in both regulated and liberalised contexts, have been designed to meet power system goals. This means that as the functions of power systems change (in response to new emerging goals), their organisational structures also change to perform the new functions.

Box 6. Evolution of the actor landscape: New, active and connected participants

From passive users to new actors. Digitalisation and the modularity of VRE and flexibility resources enable decentralisation and multilateral relations (exchange of information, energy and resources). When accompanied by conducive regulation, formerly passive agents become able to express their preferences and values through their opinion and choices regarding regulations, demand, production and provision of services to the power system. Consequently, the previously separated spaces of users and producers become blurred, as has already happened in other sectors. Challenges are ahead to implement inclusive and transparent models for meaningful participation (including data procurement and management) that build trust instead of unilaterally extracting value from users. Trust is mostly needed for developing the full potential of the new multilateral interactions. Organisational structures will need to anticipate and seek to prevent new actors facing different levels of information and entitlement compared to incumbents, especially in the initial stages of the transition.

Full inclusion and transparency. In a digitalised and distributed system, decision-making procedures can be easily shared, directly involving citizens in pursuing the public interest. It is important to design organisational structures taking into account the active participation and involvement of all stakeholders, preventing power dynamics between incumbents and newcomers. Three governance principles are essential to make participation real: a non-discriminatory environment, which is key for engagement and collaboration among actors; control and transparency to avoid asymmetric information; and participation based on a solid legal basis that recognises the added value of participation.

From unilateral to multilateral exchanges. The increasingly distributed nature of power system actors can disrupt traditional "top-down" structures and calls for a more active and collaborative power system planning, management and use. These multilateral information and energy flows pose challenges for governance and the design of organisational structures, especially when dealing with retail.

From competition to collaboration. Collaboration among a broad spectrum of existing and new players inside and outside the energy system greatly enhances the chances of success by jointly addressing the multi-level challenges of the energy transition. As the need for unlocking synergies between actors, resources, regulations and systems increases, market competition alone fails to drive the energy transition. The same happens with power system regulation when it is not informed by the wider socio-economic and planetary dimensions. Collaborative approaches are expected to play a pivotal role in driving the transition in both regulated and liberalised environments (IRENA, 2020c).

Some community-focused projects address the social responsibility dimension of the energy transition with innovative solutions based on collaboration. Examples span from the crowdfunding of solar-sourced street lightning in neighbourhoods where the power service is not reliable to facilitate safe movements; to social engagement models for community-based virtual power plants; to collective climate lawsuits against governments and companies to align policy and decision making with planetary limits.

From responsibility to empowerment. Putting to work the shared social responsibility to actively address transition challenges requires social empowerment. Empowerment is a multi-dimensional social process that assists people and communities in gaining control over their own lives, enabling people's ability to enforce change (power) and claim one's rights by acting on issues they consider to be important. To facilitate collective empowerment, a common level playing field is needed that considers that new actors can have different levels of expertise compared to incumbents.

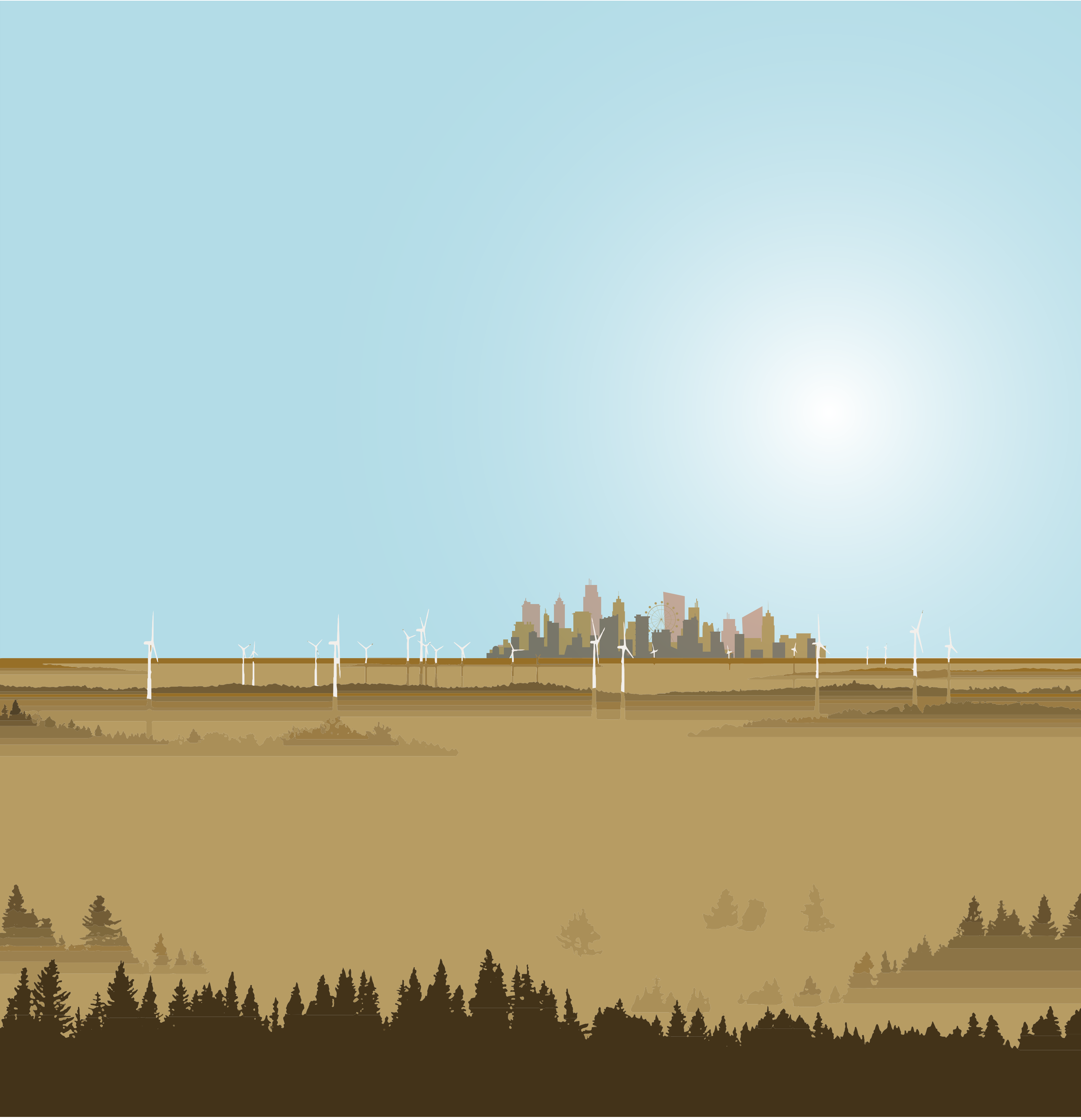
Citizens' empowerment can be facilitated in different ways, with measures that include (among many others): energy education; participation in policy making; engagement in energy or infrastructure planning; initiatives to fund renewable energy installations (including those in the Global South ,attending to the equity dimension driven by historical responsibility for the climate crisis); community-owned modern renewable energy generation; peer-to-peer finance of energy efficiency measures; and shared renewable energy-powered vehicle fleets.

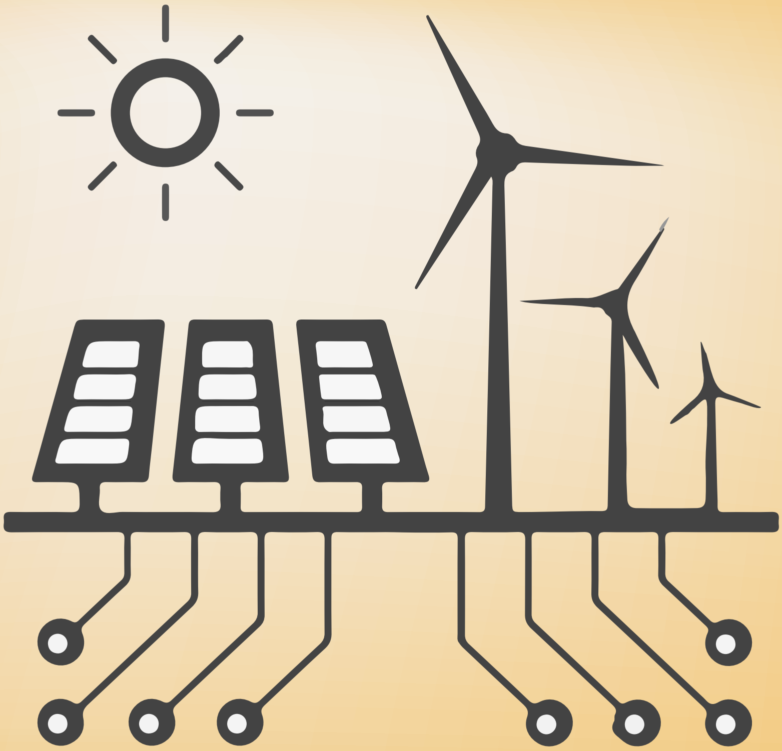
In developing and emerging economies, social empowerment can involve collaborative solutions to the lack of access to sustainable energy, such as minigrids based on solar home systems and peer-to-peer arrangements. Most importantly, empowerment makes possible initiatives outside the natural scope of utilities and incumbents, increasing the diversity and hence resilience of the system at the same time to foster disruptive innovation.

Distributed innovation. New actors – from municipalities and the recycling industry to aggregators and climate scientists – bring new expertise and ideas, improving the innovation ability of the power sector, especially when dealing with information and communications technology, digitalisation, smart contracts, sector coupling, regulation, participation mechanisms and innovative ways of capturing the full social value of power. Community-focused and distributed initiatives can deliver innovation that comes from the edges of the system (peri-systemic), locally tailored but potentially scalable to new models or organisational structures, with the aim of addressing collectively the local or global social, environmental or economic challenges, while addressing the responsibility dimension of a fair and just energy transition.

Blurring the lines between public and private towards collective initiatives. Collective initiatives may bring insightful knowledge on how to incorporate socio-environmental objectives into the power system set-up. At the same time, they can explore hybrid solutions between liberalised and regulated systems. Collective initiatives may fit within a liberalised market framework (crowd-lending, collective purchases, car sharing/pooling, etc.), evolve within the commons dimension (non-profit initiatives, financing renewable energy at zero interest or directing the benefits for the common good of the community) or have elements common to both (such as retailers who optimise their customers' contract conditions to reduce their bills in areas with high incidence of energy poverty).

Community-focused projects and pro-users have the potential to help the system by improving its resilience with their distributed assets and creating new dynamics of solidarity and mutual support. By recognising altruistic, co-operative, and collaborative engagements, organisational structures can increase both the power system and social resilience.





3 CONTEXTUALISING POWER SYSTEM STRUCTURES

If one of the main goals today is to have mostly (if not entirely) renewables-based generation, then to realise the full potential and positive contribution of renewables, power system organisational structures must be tuned to the characteristics and requirements of renewable energy. Since challenges spur from differences in technological characteristics between conventional and transition-related resources, all power systems, from the more regulated to the fully liberalised, will face them.

In some systems, the share of renewable energy in the power system has already grown substantially (Figure 9). Thanks to pro-active policy making, many countries have reached VRE shares up to 20%, and examples exist of systems with high shares of VRE (above 30%) in countries or regions such as Denmark and Uruguay.

While the deployment of renewables is progressing, the adaptation of power system organisational structures is lagging. Although for low shares of VRE this is not an issue, lack of anticipation can produce barriers to transition as the deployment of renewables progresses. Many of the potential misalignments have just begun to show up. Pro-active policy making should foresee these impediments to the energy transition and, taking stock of different countries' experiences and academic research, plan the redesign of power system organisational structures in time to avoid future hurdles. Understanding the basis of

Power system organisational structures, in both regulated and liberalised contexts, have been designed to meet power system goals. This means that as the functions of power systems change (in response to new emerging goals), their organisational structures also change to perform the new functions.

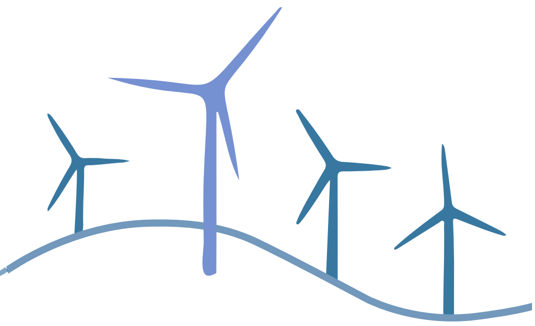
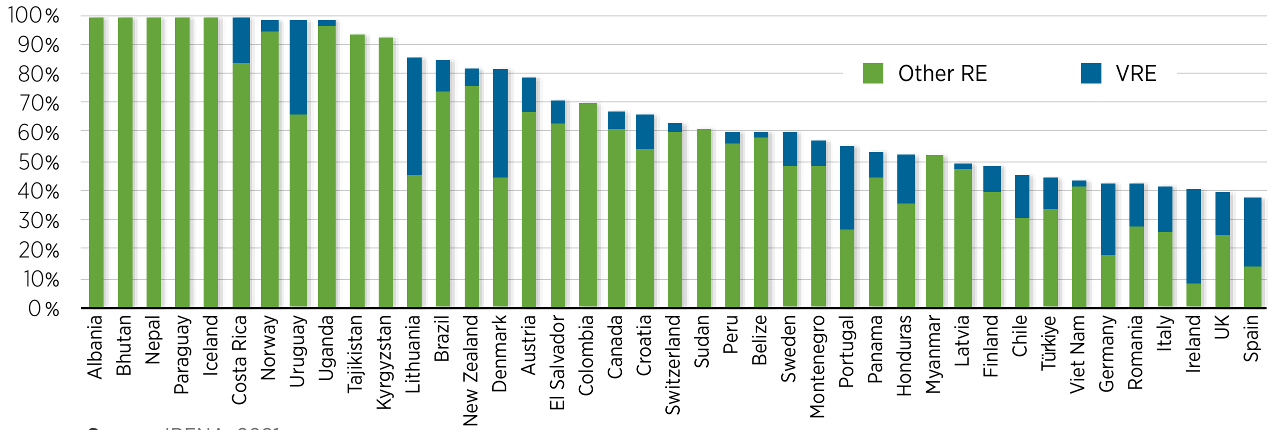


FIGURE 9. **Shares of renewable energy in final electricity consumption, selected countries, 2019**



Source: IRENA, 2021a.

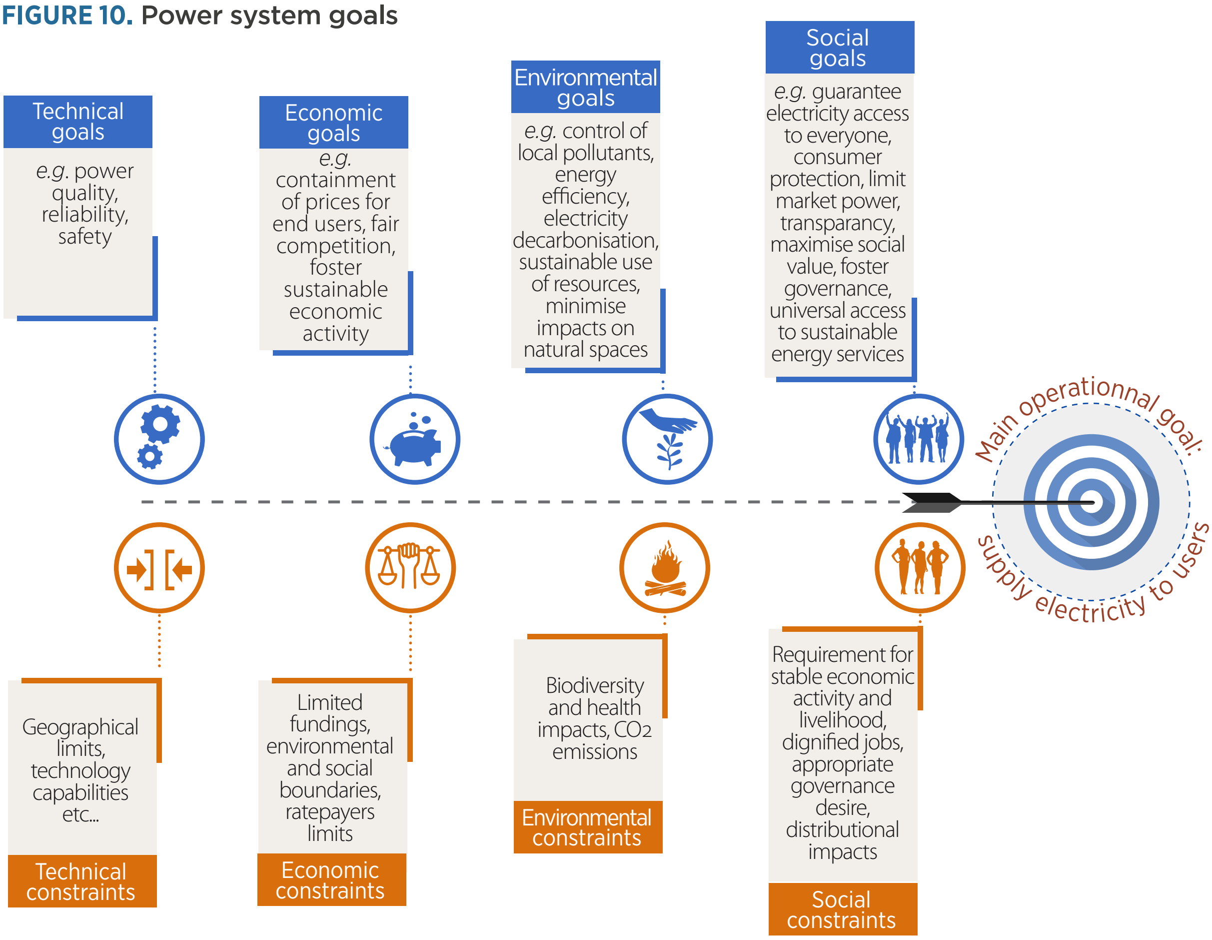
the design of these organisational structures is essential to understand what measures will be needed. The next section delves into the central aspects of power system organisational structures.

3.1. POWER SYSTEM GOALS

The power sector is vital both for the economy and for citizens' well-being. The operational goal of the power system is to guarantee the supply of electricity to users, with the ultimate objective of providing the highest possible social value. Electricity is, however, a peculiar commodity in that it must be used almost instantaneously after generation. Additional goals relate to how this electricity is supplied, and they have technical, economic, environmental and social dimensions (Figure 10). Policy objectives determine the different goals and their relative importance.

Energy authorities have been set up by countries to co-ordinate and regulate power systems, even in the more liberalised contexts. These authorities set the rules of power systems and may be energy ministries or some form of third-party entities (such as ARERA in Italy), receiving their mandate from the central government. In the case of a vertically integrated state-owned utility, the authority may be within the utility itself, which can then self-regulate in a situation of total or partial monopoly.

FIGURE 10. Power system goals



The goals and constraints presented in Figure 10 give shape to power system regulations. For example, technical goals may change the definition of ancillary services, while economic and social goals may change the way ancillary services are procured. Without proper regulation being implemented, bottom-line goals will not be achieved, and constraints will be transgressed, with the supply of electricity not providing social value.

3.2. DIFFERENT WAYS TO ORGANISE THE POWER SYSTEM

Ultimately, to achieve its goals, a power system structure should be able to procure the needed capacity and infrastructure with the required anticipation, as well as to produce and deliver electricity within the existing socio-economic and environmental boundaries.

There are different ways to organise power systems. Prevalent power system structures range from fully regulated to significantly liberalised ones. In fully regulated structures, a single utility within a region owns and operates the full set of infrastructure needed to generate, transmit and distribute energy. In fully liberalised forms, the generation and retail of electricity are open to competition, with customers being able to choose the electricity provider among available market choices.

Power grids are strongly regulated due to their condition of "natural monopoly". However, in liberalised structures, strong elements of regulation are also needed to align market outputs with power system goals. While dispatch of power plants may vary across power system models, the overall physics at the basis of the power system does not change: energy still flows from generators to users, passing through transmission and distribution grids.

The following sections present some of the main models of current power system structures. This high-level classification hides some nuances, since the level of complexity of actual power systems brings large differences in organisational structure even within the same main model. However, it provides an adequate conceptual framework. Notably, all current power system structures were designed and operated according to the goals of the fossil fuel era. No system has so far achieved a form that fits the requirements of the renewable energy era (*e.g.* to deal with very high shares of distributed and variable renewables).

The analysis focuses on regulated and liberalised systems, as the two most widely used classifications of power systems. Nevertheless, Box 7 discusses why the "regulated versus liberalised" dichotomy can be misleading.

Box 7. The "regulation versus liberalisation" dichotomy

The process experienced since the 1990s (in particular in the Global North) of opening power systems to private competition is called "liberalisation" and sometimes also referred to as "deregulation". Liberalisation involves making space for private actors to participate in the different power system tasks.

Proponents of deregulation presented it as a solution to the inefficiencies of government regulation and power system management by the state. The oft-stated rationale for deregulation is that more competition and more information could lead to higher efficiency and lower prices overall.

However, liberalisation of power markets and the entrance of competition, even single buyer models, does not necessarily result in less regulation. On the contrary, the complexity of electricity trading and dispatching, the need to maintain the system operation, the importance of electricity for a country's economy, customer protection requirements, the presence of important market failures (*e.g.* environmental externalities) and the alignment of market forces with social value introduces complex regulation requirements for the liberalised model. Energy authorities are necessary to design and implement this regulation, and establishing them is itself a non-trivial task. Energy authorities should be independent and empowered to act, while being subject to oversight and governance. In many cases, energy authorities must impose sanctions on operators that fail to comply with the requirements of the regulatory framework or that do not implement the energy authority's decisions.

Regulation in liberalised models is also needed to safeguard the interests of investors while protecting users, in such a way that the system attracts investments while making sure that private companies do not abuse their position, which by itself can result in a complex equilibrium. Regulation and the role of energy authorities is also crucial for electricity retailing. This regulation can entail control over the product allowed to be sold, the commercial tactics used by retailers, the guarantee of access to electricity for all, the treatment of energy data, metering activities, information sharing requirements, etc.

Introducing competition in the retail segment of power systems was expected to improve endogenous power system cost recovery, to open the door to innovative and more user-oriented retailing strategies, and ultimately, through overall system efficiency improvements, to reduce the final price that users pay for electricity.

Current retail structures, where distribution companies and retailers have the incentive to sell more and more energy, also show their limits in capturing the value of energy savings, flexibility and distributed resources, which may introduce barriers to transition (see chapter 4).

The prevailing retailing structures today still are not user oriented. Users normally cannot select and prioritise from which generators to buy electricity on the basis of their own preferences (including environmental, sustainability and social criteria) (Open Utility, 2016). One of the biggest shortcomings of retail power markets has been their failure to engage users (Poudineh, 2019), which would open the space for alternative approaches to emerge, such as peer-to-peer electricity markets and local matching platforms (Mujeeb, Hong and Wang, 2019; Park and Yong, 2017).

Moreover, even in the most liberalised settings, state or public control persists over many elements of the power system that are vital for its smooth operation at reasonable costs. These include transmission assets (state-controlled transmission system operators), system and market operations (controlled by public or private but heavily regulated operators) and distribution grids (often owned by local utilities). Transmission or distribution grids may be privately owned, via concessions, but state or public control over these strategic assets persists through strong regulation.

Finally, renewable energy deployment in liberalised systems in recent decades has happened mainly thanks to regulated payments (see section 3.4), which reintroduced regulation for dedicated and state-driven procurement of specific technologies, overriding competitive markets.

On the other hand, regulated systems can also incorporate competitive components such as auctioned power purchase agreements with independent power producers (IPPs) or tenders to build new infrastructure.

For these reasons, the "regulated versus liberalised" dichotomy, although commonly used, can be misleading. Regulation is set to remain at the core of any power system organisational structure, as a fundamental component to steer power systems towards social value creation. Thus, by way of clarification, when regulated organisational structure set-ups are mentioned in this document, it is not understood that these are the only ones to be guided by regulation, but rather those in which regulated generation and retail operations are not open to competition.

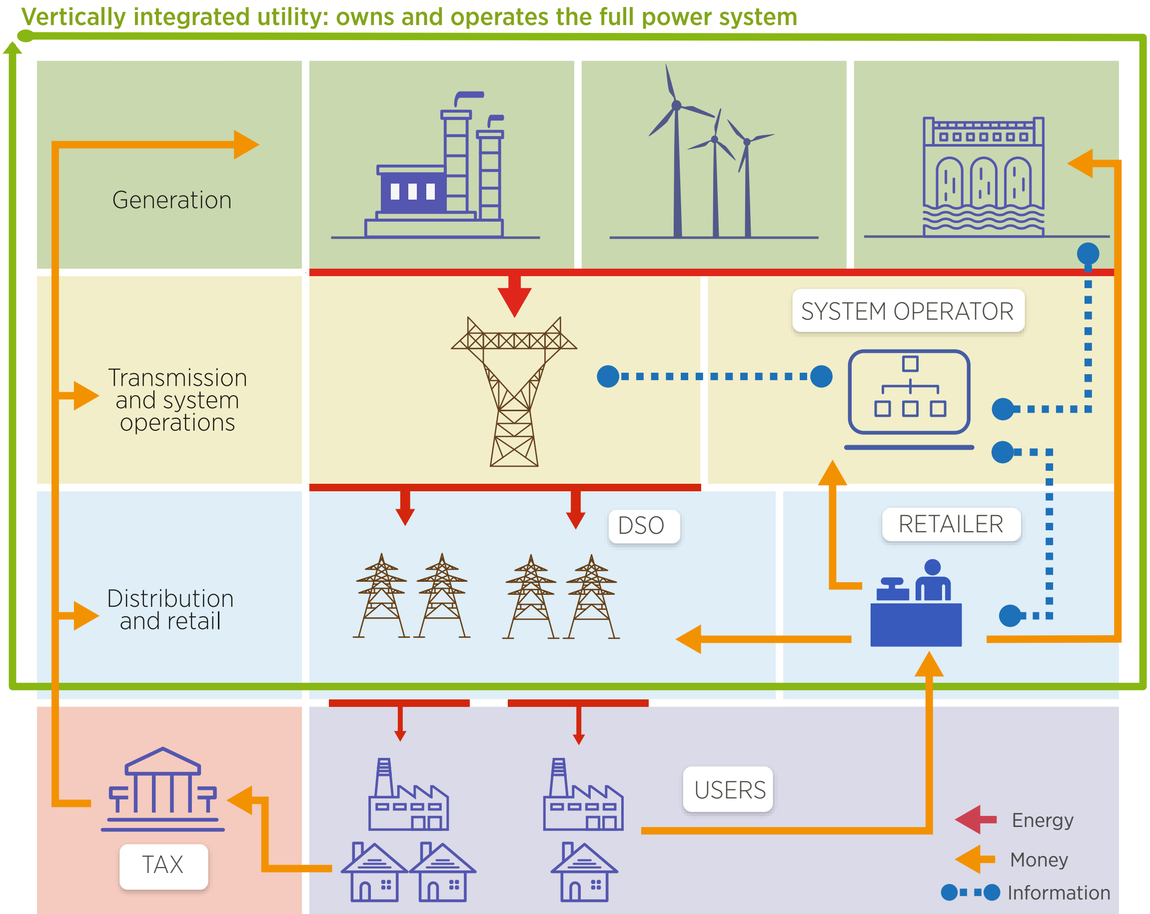
Source: EEU, 2020; Kessides, 2004; OFGEM, 2020; Thomas, 2004.

Regulated power system structures

Historically, the power sector was dominated by Vertically Integrated Utilities (VIUs). They had a monopoly over all activities in the generation, transmission and distribution of power within the system's geographical domain of operation. This model still persists in some parts of the world, including in parts of the United States, Africa and Asia. Regulated utilities can be publicly or privately owned.

The flow of electricity passes from generation to the transmission grid, and then to distribution grids. Operations are supervised by a system operator, which manages the entire grid from one or more control centres. In regulated systems, the utility is assured a fair return on its investment (at all levels of generation, transmission, distribution and supply), once it conforms to the regulatory guidelines and practices set by the energy regulator. The energy authority sets the tariffs for all users. Users pay the regulated tariffs to the utility, which is the sole vendor of electricity. Other revenue streams fed by general taxation may complement those from regulated electricity tariffs (Figure 11).

FIGURE 11. Regulated power system – illustrative



Vertically Integrated utility model

The VIIU model offered a low-risk solution to finance the kickstart of national power industries, in a time when electricity provision was understood foremost to be a public service. Vertical integration refers to the integration of the layers of generation, transmission, distribution and supply into one single utility.

VIUs, freed from the hassle of profit making and competition, could focus on building up power systems. The investments required large capital for infrastructure. A local monopoly and a stable and growing demand minimised risks and maximised the ability to harvest the benefits of economies of scale in infrastructure.

Single buyer model

In many countries, VIUs can now purchase electricity from independent power producers (IPPs) as a single buyer. An IPP owns and operates one or more power plants and sells their output to the local utility, which buys electricity as agreed in a power purchase agreement (Box 8). There are no direct changes for users, as the VIU remains the only retailer of electricity, but users may experience indirect impacts from the single buyer model through retail pricing and social implications of electricity procurement costs.

The single buyer model introduces a layer of competition, since the single buyer (which can be a public body or the VIU itself) can use competitive bidding processes to allocate power purchase agreements, for example via auctions. These auctions have a bidding framework and terms of reference produced by the single buyer and the government. Through them, the single buyer or the government can introduce procurement goals, which can go far beyond price minimisation (IRENA, 2019b).

In some countries, such as in Pakistan, the single buyer model has been implemented as a first stage in power sector reform towards increasing competition (liberalisation). In other cases, such as South Africa, the single buyer model has been used to attract private financing of new generation capacity.

Box 8. Power purchase agreements

The single buyer model mainly relies on power purchase agreements (PPAs). These are bilateral contracts between a generator of electricity – sometimes referred to as an independent power producer (IPP) – and a buyer of electricity, which may be the utility, a retailer or a large consumer.

The PPA defines all the commercial terms for the sale of electricity between the two parties and is usually limited in time. Many forms of PPAs are in use today, and they vary according to the needs of the buyer or the seller, and of the financing counterparties. In any case, the PPA is regulated by the energy authority and the national utility or transmission system operator, which need to be informed and in some cases to authorise the PPAs. This is because electricity transacted through the PPA needs the transmission and distribution grids to be exchanged.

PPAs embed significant risk re-allocation components, with their impacts in the price seen by users depending on their balance. Power plant operational and investment risks are transferred to the IPP, which will price it into its PPA offer. The long-term nature of the pricing mechanism reduces revenue risks for the IPP, since purchased quantities and prices tend to be established.

In the pure single buyer model, the PPA is signed between an IPP and the state utility, which acts as buyer. In other models, buyers of electricity can also be retailers of electricity (who buy it from the IPP to then sell it to final consumers), large consumers or aggregators of small users. PPAs reduce market price risks for users, which is why large consumers frequently sign them. Moreover, in securing a long-term buyer and electricity price, PPAs can reduce power plant investment costs by reducing investors' risks and hence the cost of capital.

PPAs between private parties also allow users to know the electricity source and to foster the environmental or social value of electricity production. Many corporate consumers of electricity from a breadth of economic sectors are increasingly turning to renewables as their preferred energy choice, using PPAs to ensure the renewable origin of the purchased electricity.

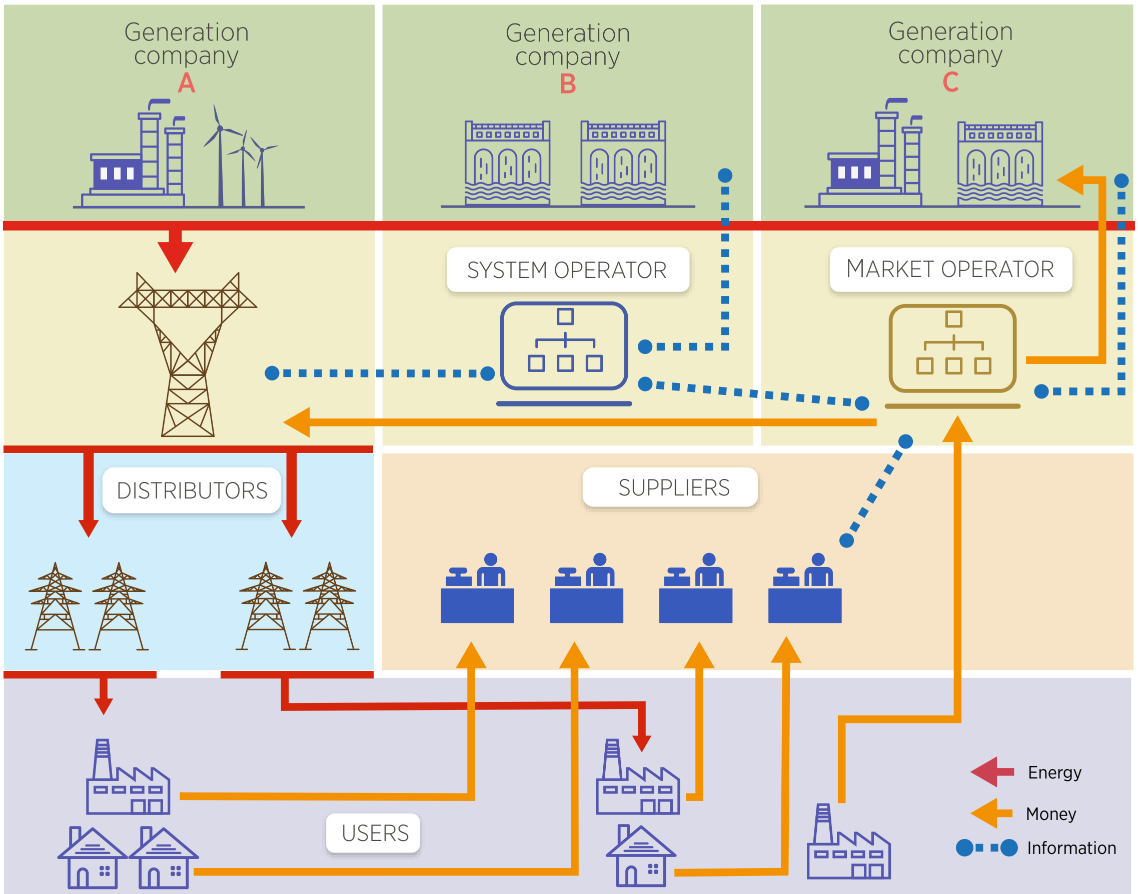
PPAs have been used in both regulated and liberalised structures. In regulated organisational structures, PPAs introduce a competitive component in wholesale electricity procurement. In liberalised organisational structures, they introduce a regulated component in wholesale electricity procurement.

Liberalised power system structures

The creation of competitive electricity markets, aiming to induce efficiencies by introducing competition, is at the core of liberalised models for the power system (see chapter 5 and box 7).

Liberalised models can imply two different markets: the wholesale market and the retail market. The latter is sometimes not completely implemented, with protected users (usually residential households) having electricity supplied by a regulated retailer. Liberalised models necessitate the vertical and horizontal unbundling of the VIU (Box 9), as well as the privatisation of some or all formerly state-owned generation assets (Figure 12).

FIGURE 12. Liberalised power system structures – illustrative



Liberalised systems have a market operator (in some cases overlapping with the system operator) that has the role of collecting bids from generators and buyers of wholesale electricity (retailers and large consumers), and to order them on the basis of their economic offers and clear the market in each trading period (*e.g.* hour or quarter-hour). The system operator determines the final physical dispatch of the power plants once the wholesale market is cleared.

Box 9. Unbundling the power system

"Unbundling" is a structural reform that involves the separation of core functions performed by the VIU.

Vertical unbundling is the organisational separation of the main power system operations (generation, transmission and distribution/ retail). The generation fleet would be given to one or several generation companies, while the operations of the transmission assets would be given to the transmission system operator (TSO) or to an independent system operator (ISO), and the physical assets may be owned by another transmission company. Distribution grids would be assigned to multiple distribution system operators acting in different geographical areas, often overseen by local jurisdictions, which in initial stages often act also as retailers to final consumers and tariff collectors (Figure 12): each distribution system operator controls and operates the distribution grid under its supervision.

Horizontal unbundling of the generation layer is the separation of generation into different entities, which may be either private or state-owned companies and, within a liberalised power system, compete to generate electricity (Figure 13). The retail activity can be split among different retailers (no longer tied to the distribution operations) that in liberalised systems compete to supply electricity and other services to users. Retailers resell the electricity (that they bought in the wholesale market) to users in the retail market and compete to gain market shares of users.

FIGURE 13. Vertical unbundling of the power system – illustrative

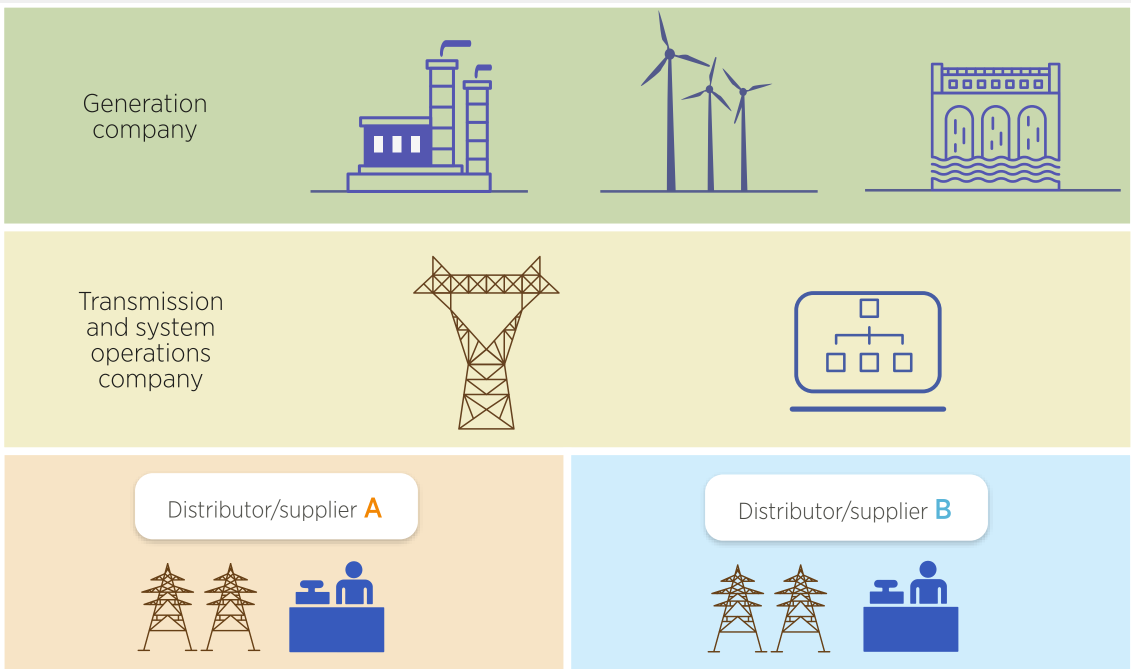
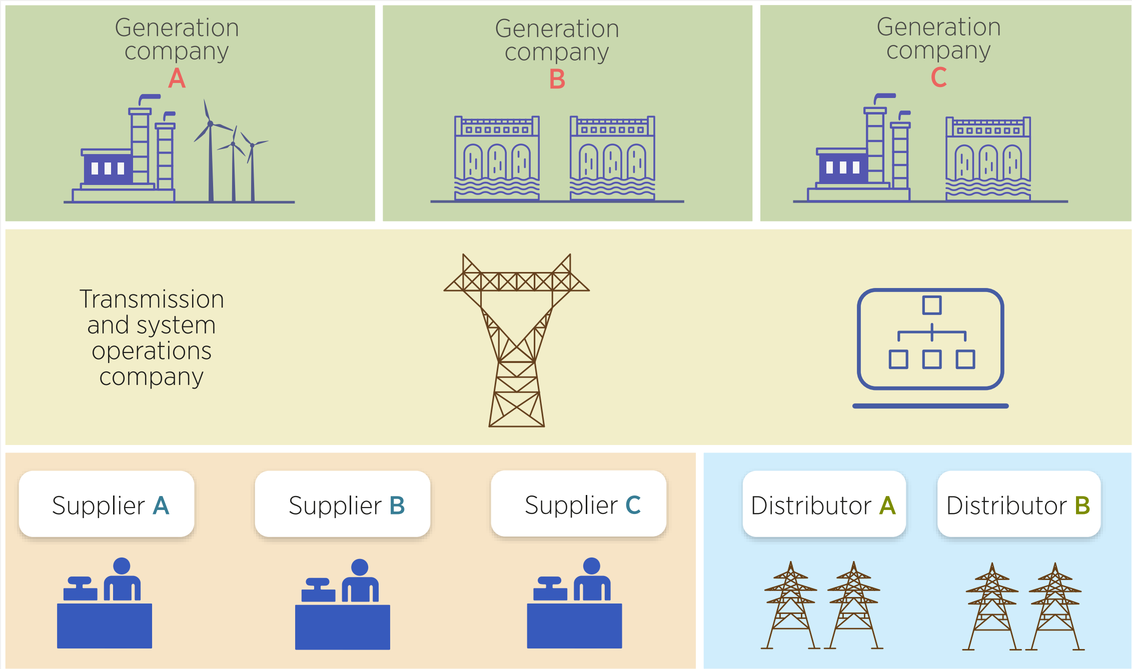


FIGURE 14. **Horizontal unbundling of the generation and distribution/retail power system layers – illustrative**



Drivers for unbundling have been various. One major economic reason for unbundling has been the reduction of agency costs arising from over- or under-investment. Horizontal unbundling often has been enacted to increase competition in generation and retail, with the expectation of this increasing efficiency and reducing overall costs to final users. Vertical unbundling is required first to prevent cross financing of regulated and non-regulated activities and to prevent market power positions by joining generation and retail; moreover, it can allow for non-discriminatory access to electricity grids and greater transparency on financial management and accounting within the system. The role of regulation in unbundling is to guarantee governance and alignment with social value creation, improving transparency and supervision of the activities of all the players (public or private).

Wholesale market

A wholesale electricity market is where competing generators offer their electricity output to energy retailers and large consumers. Energy authorities and policy makers designed wholesale markets to address the issues deemed more relevant at the time of their creation. This led to different designs, mirroring jurisdictions' differences in terms of geography, power system topology and policy makers' objectives.

The market operator is an independent regulated entity that conducts market clearing that, in turn determines market prices for energy generation. Aside from energy generation, power plants called by the system operator to perform ancillary or balancing services have another revenue stream associated with these services. Additional regulated remunerations for generation can also be introduced (such as capacity mechanisms, feed-in tariffs or others). How the market operator works varies across jurisdictions. Two main groups are worth mentioning, however: **transmission system operator (TSO) systems** and **independent system operator (ISO) systems** (Box 10).

Box 10. Transmission system operator and independent system operator systems

In TSO systems, typical of Europe, the market operator and the TSO are clearly separated entities. The TSO is an entity (state-owned or otherwise) responsible for controlling and operating the transmission grid. The objective of the TSO is to guarantee power system security in real time. The market operator has the role of centrally trading electricity and calculating electricity prices, clearing the market based on bids from generators and buyers, but without considering network constraints.

Every day, the market operator passes the generation schedule to the TSO. If, after trading, the network is foreseen to be congested, the TSO, given its role to maintain grid security, can "re-dispatch", meaning that it requires power plants to adjust the power feed-in to avoid or resolve congestions. All of these re-dispatch measures result in extra costs for consumers: when a TSO tells power stations to limit production, it must still compensate them for the power they would have been paid for, and power stations that TSOs ask to produce extra power do so at costs higher than the market price.

An alternative solution is given by ISO systems, characteristic of the United States. The ISO conducts the two functions of market operator and system operator.* The ISO collects the complex bids and the information of all resources in the grid, as well as the state of the transmission system, and instructs power plants when and how to operate in order to minimise costs and grid congestions. This eliminates the necessity for re-dispatching found in TSO systems, and offers wider room for operational optimisation. This happens at the sake of transparency and requiring more complex bids for participants. ISOs have a high degree of centralisation, with direct control over the system resources at any point in time. Hence, ISOs need to have high temporal and geographical visibility of the power system (Green, 2007; Neuhoff and Boyd, 2011).

* In some cases, the entity may be known by other terms, such as regional transmission organisation (RTO). For the purpose of this report, ISOs are intended to lump together cases where system operators act also as market operators

Retail market

Liberalisation of retail activity was proposed after the introduction of competitive wholesale markets as a means to pass on the potential benefits of competition to end users. The retail electricity market plays a key role in liberalised power systems as retailers become the main contact point between end users and the power system, as well as one of the main means for users to influence the power system.

In liberalised retail markets, end users can buy electricity from private retailers of electricity, who previously bought electricity in wholesale markets, in future markets, or from their own assets or from IPPs via PPAs. Retailers differentiate among themselves through prices, tariff structures and other value-added services that they can provide to final users, including the sustainability of the electricity they sell.

Final users, through their bills, are expected to cover the costs of the whole power system and the economic profits of the different agents serving it (both regulated and liberalised activities). Notably, this includes all power system activities (generation, transmission, distribution and retail). For this reason, electricity bills include different cost items, some of them variable based on the amount of electricity consumed and others fixed as a function of the contracted capacity, or per user. In many cases, final users, in particular residential ones, have the option to buy electricity from a state-owned or privately owned regulated energy retailer, which offers regulated rates.

3.3. ELEMENTS OF POWER SYSTEM STRUCTURES

Power system organisational structures will need to change in order to host large shares of renewable energy (see chapter 4). However, the transition of the power sector builds on its existing elements, developed and improved over time. This section describes the elements of the power system to enable a better understanding of the remaining sections: what, why and how changes should be introduced to evolve from the fossil fuel era to the renewables era.

Why specific structures? Electricity characteristics

Electricity has unique characteristics that require specific organisational structures. These characteristics are the following:

1) Electricity cannot be largely stored. Most of the energy products (biomass, coal, oil, gas, etc.) can be stored, which allows retailers to smooth out peaks in demand and prices by drawing down stores when prices are high and building stores when prices are low. Electricity can be converted and stored in hydropower pumped storage plants, in batteries, and as hydrogen or heat, but the storage capacity around the world is very small compared to the installed capacity. Moreover, any energy storage implies a loss of electricity, resulting in less electricity delivered than produced.

2) Constant match of supply and demand. In a power system, supply and demand must match in any moment, or the whole system or part of it would collapse. This constraint requires a considerable level of system operator control over generators and demand.

3) Electrons are non-distinguishable. Electricity served to the final users is an entirely standardised product, and renewable or fossil fuel generation cannot be distinguished at the socket. Hence swapping between retailers does not change the characteristics of the electricity served, although it can indirectly influence generation. For the same reason, a credible design of renewable electricity certification is a challenging issue.

4) There are no substitutes. Power-driven equipment cannot receive anything but standardised electricity as an input. Migrating to another form of final energy is possible only with (often expensive) equipment substitution, which is not always an option in either households, commercial buildings or industry. Some sectors, such as information technology, cannot use anything but electricity.

5) Massive impact on society. A long-standing failure of the power system will lead to immediate and severe welfare and economic impacts. Governments act to avoid the risk of power industry failure.

6) Large environmental impact. Power generation has an immediate environmental impact, and regulation exists in many instances to limit this impact. Moreover, electricity generation plays a crucial role in greenhouse gas emissions, and attempts to deal with the climate emergency have so far focused mainly on the power sector.

Given these peculiar characteristics, power systems and their organisational structures have been conceived to be able to deliver electricity to final users in a continuous way, driven by demand and with little control over users' behaviour. For these reasons, comparisons with other sectors, such as telecommunications, fall short in describing potential solutions.

The procurement mechanisms

To guarantee a reliable matching of demand and supply at each point in time, any power system structure envisages multiple trading or allocation mechanisms (Figure 15). These are designed to gradually reduce uncertainty and the mismatch between generation and demand, so that these two become perfectly matched at each point in time.

Supply arrangements can happen years in advance, using PPAs with IPPs, capacity payments or public procurement of generation plants, to guarantee the forecasted electricity supply needs.

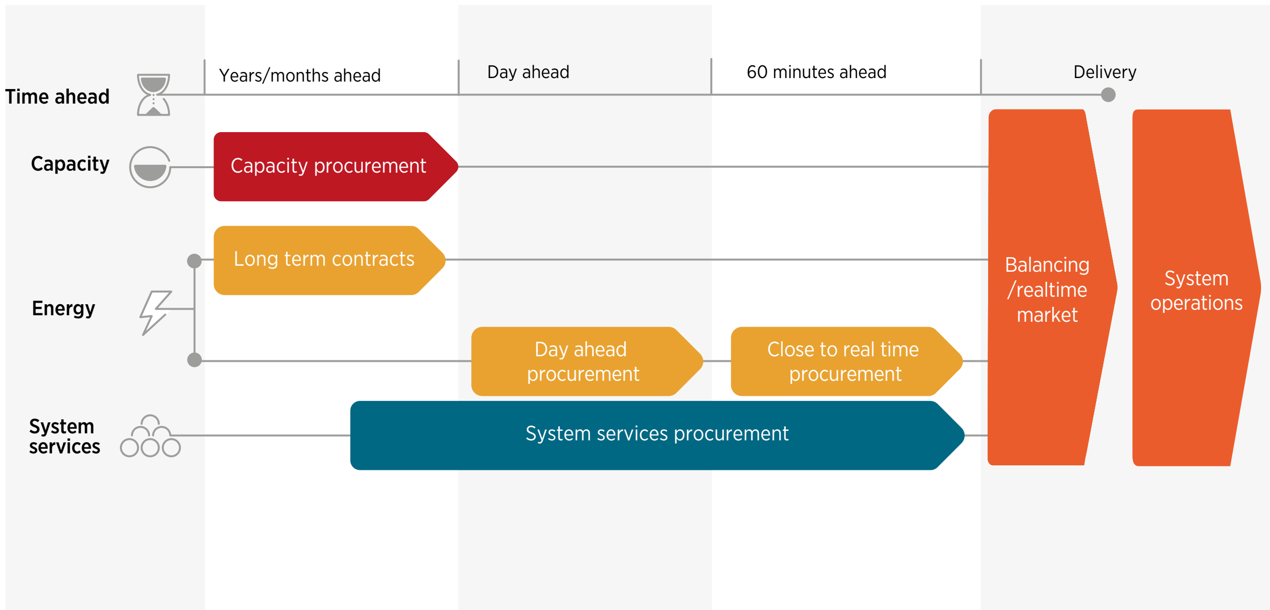
Closer to actual dispatch, procurement mechanisms have been designed to match production and the remaining consumption of electricity (not covered by the long-term supply arrangements) with different time frames, allocating the provision of generation and services across the available portfolio.

Day-ahead procurement (market or otherwise) is when most of the arrangements are being made. Still, uncertainty remains, such that close to real time (a few minutes before dispatch) additional actions are needed to settle the last differences between supply and demand.

Having full system control over the very short term before dispatch, system operators procure the system services needed for a reliable supply. System services are used to maintain the grid's ability to properly operate even with very last-second deviations.

The main elements composing power system organisational structures are described in the next sections.

FIGURE 15. Main elements of power system procurement mechanism



Based on: IRENA, IEA and REN21, 2018.

Energy procurement

Long-term contracts

In regulated systems, the investment in power plants by VIUs is based on long-term planning. Power plants receive a pre-established regulated remuneration (given each power plant's technical characteristics and cost functions) for its production along its whole life.

Long-term procurement of electricity in both regulated and liberalised systems also may happen through PPAs, when regulation allows this option (Box 8).

The PPAs can be signed between an IPP and a VIU, as in the aforementioned single buyer model. In this case, contacts and risk allocation are standardised and regulated.

When the power purchase agreements are between private entities, and do not follow a standardised format, this can create a so-called over-the-counter (OTC) market. In the OTC market, counterparties reach an agreement and directly trade electricity among themselves. These contracts influence actual overall system dispatching, and the system operator needs to be notified.

Finally, long-term energy procurement may also happen through support mechanisms for renewable energy providing additional regulated payments, such as feed-in tariffs and auctions. In these cases, a long-term PPA or feed-in tariff contract is signed for a regulated payment. These are discussed in section 3.4. The effects of such contracts on the overall power system are discussed in chapter 4.

Hence long-term procurement electricity mechanisms are already present in today's power system organisational structures, but in most cases[14] they affect only a small share of total system energy. Chapter 6 presents a proposal for an organisational structure adequate for a renewable-based energy system that uses long-term procurement mechanisms as one of its main pillars.

Short-term procurement

Short-term procurement refers to the activities to select the power plants' generating electricity (dispatch), from one week to one day before delivery. Some uncertainty remains after the short-term procurement mechanism commits generators: the goal of these mechanisms is to allocate the bulk of the generation and leave only small adjustments as the delivery moment approaches. Staggered allocation mechanisms are often used to gradually reduce uncertainty in the needed dispatch. While each power system structure has its own suite of decision-making processes, some common aspects can be found.

Regulated systems: Unit commitment

In regulated systems, unit commitment is the process through which a VIU decides which of its power generating units should operate at any given time.

Unit commitment aims at supplying an estimated demand profile at the lowest cost, given each power plant's technical characteristics and cost functions, considering system details such as power plants' start-up and shut-down timings and costs, the hydrological restrictions and the generating capacity to be held in reserve for system services.

Unit commitment is applied by the VIU within different time scales, depending on system characteristics. For example, the Indonesian utility PLN runs several unit commitment schedules, from one month to one day before delivery, for each of the main eight islands.

[14] The exception would be fully regulated systems, often combining public investment and competitive IPP's' power purchase agreements for VRE technologies.

Hybrid systems: Markets based on audited costs

In some cases, the decision on unit commitment happens via another regulated operation, with a decision-making procedure that takes into account the audited costs of generating units.

In these cases, some level of liberalisation may be in place, with private generators able to sell to a market operator their power production. The scheduling of power plants, however, depends on an algorithm based on the "audited costs", meaning a set of information gathered by the market operator at a plant level. The market operator decides (using simulation tools that use as inputs the audited plant costs) how plants will operate, on the grounds of marginal pricing to reduce operation costs and medium- to long-term optimisation criteria. A practical example is Brazil (Box 11).

Regulators that favour an audited cost-based design argue that this is more appropriate for systems with a small number of generation firms, since it eliminates the possibilities for generators to behave strategically in a bid-based market, which is a main concern in such markets (see next section).

Box 11. The Brazilian case

In a hydropower-dominated power system, as in Brazil, power plant scheduling is guided primarily by water levels in the various reservoirs, with the objective of limiting the risk of possible water shortages in the future. VRE sources are dispatched first, since they do not have any fuel-related cost and do not impact water reservoirs. The use of hydropower is decided via a trade-off between avoiding the need for more expensive thermal power plants and the risk of drought.

The Operador Nacional do Sistema Eléctrico (ONS) sets the power plant scheduling to minimise total costs using simulation models. ONS uses the "DESSEM" model to determine the daily dispatch schedule one week ahead, in 30-minute blocks, taking into account all information on generation plants, grid constraints and over-the-counter (OTC) exchanges.

Liberalised systems: Bid-based markets

Bid-based markets are the cornerstone of liberalised models, in both ISO and TSO models. In such models, generators compete to sell their energy to a set of potential buyers, which include large consumers, pools of small consumers, and private or state-owned retailers. Since in liberalised systems the markets close one day before delivery, they are known as **day-ahead markets**.

The design of day-ahead markets has been permanently evolving over time, in part to address some of the challenges of the energy transition (see chapter 4). Different countries have developed a variety of market models. All the liberalised models, however, are based on marginal pricing (Box 12).

All markets clear the prices for a certain trading interval (from five minutes to one hour) by matching bids of generators and buyers. This can be achieved in different ways, with simple or more complex bidding structures, with portfolio bids, with a uniform national price, or with zonal or nodal prices, etc.

Box 12. Marginal pricing and scarcity events

MARGINAL PRICING

Marginal pricing is at the core of current liberalised power systems.

For each trading interval, which could span from one hour to five minutes, all the generators are stacked in a curve – the supply curve – depending on their bids (or the information regarding their marginal costs structure audited by the market operator in cost-based models). The demand curve, composed by the buyers' bids (which indicates the volume of electricity desired and the amount they are willing to pay) meets the supply curve at a certain point, which determines the capacity committed and the wholesale price.

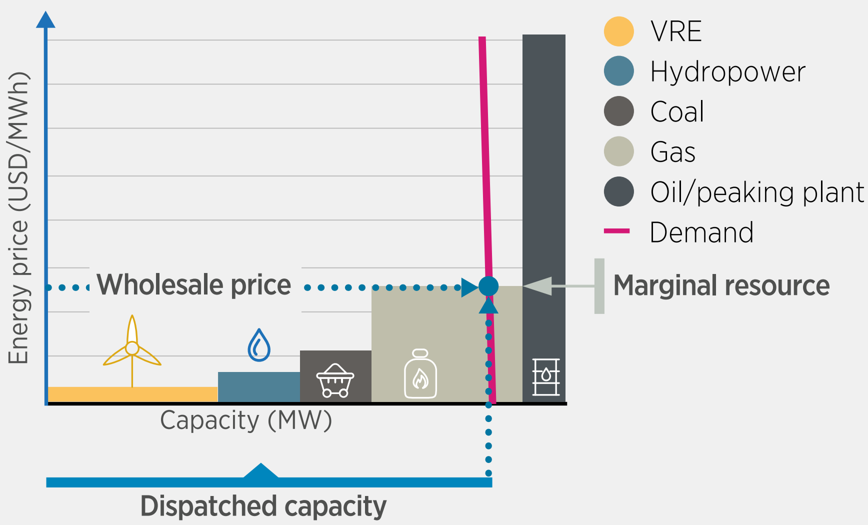
The electricity price at each moment in time is the marginal price (set by the resource in the supply curve that would satisfy a possible increment of electricity demand – the marginal resource). All selected generators, marginal or otherwise, then receive this same wholesale price (Figure 16).

The supply curve is built in different ways in cost-based models and in bid-based models. In cost-based models, the system operator is informed about the cost incurred by all generators and builds the supply curve (merit order) based on this information, which allows for minimising the system operational costs.

Within bid-based models, the clearance of the wholesale market is conducted in different ways in ISO and TSO models. In the ISO model, the ISO requires resource operators to submit complex multi-part bids to represent the detailed operational and opportunity costs as well as the technical constraints of their units. With these data, together with information about grid capabilities and constraints, the ISO calculates the least-cost dispatch mix of the power plants, using an algorithm that aims to find the best solution for each node at each point in time, and taking into account both the electricity supply and the supply of ancillary services.

In the TSO model, wholesale markets were initially envisioned as simple electricity auctions, without control over the actual technical feasibility of the cleared schedule. Once the market is cleared, if the system operator identifies potential grid congestion, it can re-dispatch generation to keep the system reliable. Nowadays, many wholesale markets also allow complex bids.

FIGURE 16. **Marginal pricing**



In general, under competitive conditions, bids reflect marginal cost, a combination of operational (where fuel is the main component) and opportunity costs. In this way, a generator is sure to at least not incur losses. If a power plant is selected to participate and is not the marginal resource, the differential between the wholesale price (the marginal price of the marginal resource) and its marginal cost provides an income buffer that allows recovery of the fixed and investment costs. If a power plant is selected to be the marginal resource, it should not have either gains or losses, in terms of marginal costs.

Renewable energy generators do not fit well into this pricing structure, especially as their penetration of renewables increases (see section 4.2). This is because they have limited dispatchability and very low operational costs, and the cost structure is dominated by investment costs. Despite sitting on the left of the merit order supply curve (Figure 17), their investment costs are currently mainly recovered through additional regulated payments.

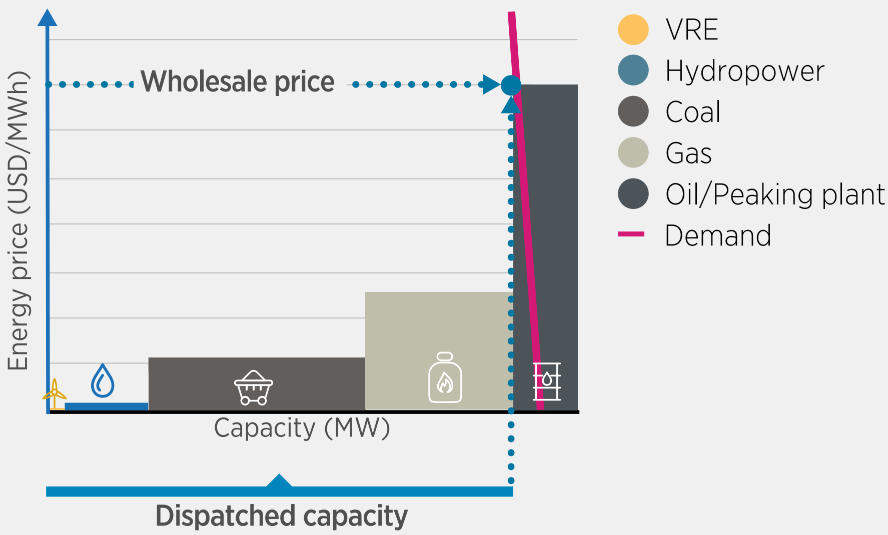
Investment costs of marginal resources are recovered in the so-called scarcity events.

SCARCITY EVENT

Scarcity events are hours of high demand and low available supply. During these events, prices are set by those power plants that are used only a few hours a year, such as diesel oil, which bid much above their operational costs (in the order of thousands of USD per megawatt hour (MWh)). During scarcity events, marginal resources (usually natural gas plants) also typically can recover their investment costs.

During scarcity events, the price should spike up to the maximum price for electricity that consumers may be willing to pay to avoid a black-out or a reduction in energy consumption. However, consumers have limited and indirect participation in such markets, and scarcity pricing is often capped administratively in wholesale markets for socio-political acceptance and to prevent the exercise of market power. The misalignment created by this cap is discussed in chapter 4.

FIGURE 17. Scarcity event



Close to real time

Once the short-term procurement mechanisms are closed and the bulk of power generation is committed, additional mechanisms (*e.g.* intraday markets) allow all stakeholders to fix any deviations that might occur from the programme.

Deviations from the scheduled programme can happen for a variety of reasons: last-minute plant shutdowns or changes to their forecasted production, congestion on interconnectors between countries, unexpected variations in the demand scheduled or demand-side resources unable to adjust their consumption as committed, and cold or hot waves that change consumption profiles. Recently, with the increasing presence of VRE in power systems, the impact of weather uncertainty on the scheduling of the power system has increased.

Deviations from the planned dispatch are directly managed by system operators by re-dispatching them using different mechanisms. As a last resource when the delivery time approaches, system operators re-dispatch deviations using resources that make themselves available to supply ancillary services (see below).

Regulated systems: Real-time re-dispatch

In a regulated system, where the majority or all the generation assets are owned and controlled by the same utility, the system operator keeps overseeing the system conditions, being informed by asset operators about changes and by the updated weather forecast.

Using a dedicated algorithm, real-time dispatch activity by the system operator adjusts the schedule from the previous unit commitment based on the revised input data and the real-time network model, taking into account transmission, distribution, generation and demand-side constraints.

Each generator or demand-side resource is then informed of the output (or response in the case of the demand-side resource) that it should provide.

ISO systems: Real-time market

In ISO systems, the ISO manages the real-time market to continuously balance the dispatch of resources to meet the real-time demand for electricity. If a participant in the day-ahead market deviates from the schedule, it is charged to reflect the amount of deviated supply or demand. The price from the real-time market is calculated usually every few minutes through a unit commitment-like model taking into account the actual conditions of the system. The model re-commits power plants to cover the deviations and optimise the fleet to have system services ready in case of necessity (see next section) In the United States, the day-ahead and the real-time markets make up the so-called two-settlement system. According to the Federal Energy Regulatory Commission, 95% of transactions are agreed upon in the day-ahead market, leaving only 5% to be scheduled in the real-time market (FERC, 2016).

TSO systems: Intraday markets

The intraday markets are mechanisms in place in liberalised TSO systems, organised by the market operators. Their design differs among countries.[15]

The need for intraday markets is linked to the fact that deviations from the scheduled commitments from short-term markets are penalised by the system operators. The intraday market, therefore, helps reduce the risk of being penalised for the imbalances by allowing generation and demand to adjust its offers with reducing uncertainty as delivery time approaches.

[15] For more detailed examples of intraday markets, see IRENA (2017)

Participants can trade electricity among themselves in intraday markets to address excess or deficit from the commitments, and hence avoid or minimise penalisations. Intraday markets allow participants to make adjustments to their schedules. This market creates new financially binding contracts between participants.

Ancillary services procurement

Ancillary services are services provided by power system resources (which could be generators, storage plants or demand-side resources), on different time scales, to support the system operator in guaranteeing the continuous and reliable operation of the power system.[16]

Ancillary services have different names depending on the power systems, but generally can be grouped into four categories:

- **system management services** to ensure secure, efficient operation and monitoring of the electricity system (for example, interruptibility services);
- **frequency control services** that guarantee the match between generation and demand at any given time (addressing deviations close to delivery time);
- **voltage control services** that are used to maintain the voltage level in the range of permissible values; and
- **system restoration services** that system operators can use in emergencies to restore the electricity supply as quickly as possible after a failure affecting part or all of the electricity system.

The procurement of system services happens from one year to a few hours before delivery, depending on the country and service. Resources able to provide system services commit to intervening in the system (injecting power, shedding a load, charging a battery, etc.) within a specific time frame after the request of the system operator. In a VIU system, where the utility owns and operates all the assets, generators' operations are optimised to maintain some resources able to provide these services if needed.

In some liberalised systems, some ancillary services may not be directly rewarded to private generators. System participants are required to be able to provide such services in order to enter the market.

In ISO models, the real-time market is designed to also procure system services and optimise their procurement with close-to-real-time adjustments. In TSO models, competitive tendering and bilateral contracts on an annual, monthly or weekly basis are the more common schemes for procuring system services.

Capacity procurement

Both regulated and liberalised systems implement mechanisms to guarantee that the needed generation capacity to properly and reliably operate the power system will be available. In regulated systems these mechanisms are linked to central energy planning, whereby investment is undertaken to guarantee that the system has the capacity to supply the forecasted electricity demand. In liberalised systems capacity procurement is more complex because of its reliance on wholesale electricity markets to trigger investments, and the discrepancy between the signals that these markets provide to investors and the reliability needs of the power system. The energy transition intensifies these discrepancies and has triggered an increased reliance on capacity markets.

[16] For more details and suggestions for modern system services, see IRENA (2019c).

Capacity mechanisms provide guaranteed payments to power plants for having the "firm capacity" to produce electricity. The system operator buys capacity availability years ahead of delivery via mechanisms similar to auctions, with the aim of ensuring that there is sufficient investment in the development of new generation to meet reliability standards. Capacity market agreement holders receive a standard "capacity payment" (a payment per megawatt available) and have the obligation to guarantee the availability of contracted capacity during a certain period. The system operator can then request the activation of the power plant.

Capacity mechanisms were initially designed to procure capacity availability and keep the system reliable, in particular for systems struggling to attract investors through short-term markets and with substantial under-capacity (McRae and Wolak, 2019). Notably, not all systems have these kinds of mechanisms.

However, capacity mechanisms emerged as an opportunity for generators who are unable to recover their invested costs from selling electricity in a system based on marginal pricing. Indeed, the increasing penetration of VRE reduces the average wholesale prices and the volume of electricity sold by other technologies, thereby reducing the options for new or upcoming generators to recover their invested costs (section 4.2). Capacity markets provide the possibility for dispatchable generators to recover their invested cost by supplementing the revenues they get in VRE-rich short-term energy markets with an additional revenue stream.

Policy makers must make sure that capacity markets are used for their original purpose – to maintain system reliability – and not to produce barriers to transition by keeping online rent-seeking fossil fuel power plants that have to eventually be phased out during the energy transition.

Retail of energy

The costs incurred by the system need to be recovered in order to have an economically sustainable power system. These include generation costs (which may have subsidy or additionally regulated payment components; see next sections), transmission and distribution costs, supply costs, as well as the cost incurred to procure system capacity and to run the whole system (*e.g.* remuneration for system and market operators performing their duties). In the case of liberalised power systems, benefit margins for all agents involved in power system operation are also included in system costs.

In general, there are two ways that power system costs can be recovered: electricity bills and general taxation. Today, the prevailing aim is to recover most power system costs through electricity bills, although some can still be recovered through general taxation (*i.e.* subsidies to address energy poverty); however, in the past the balance has been different. Likewise, electricity consumption is taxed and hence helps to produce revenue for government spending.

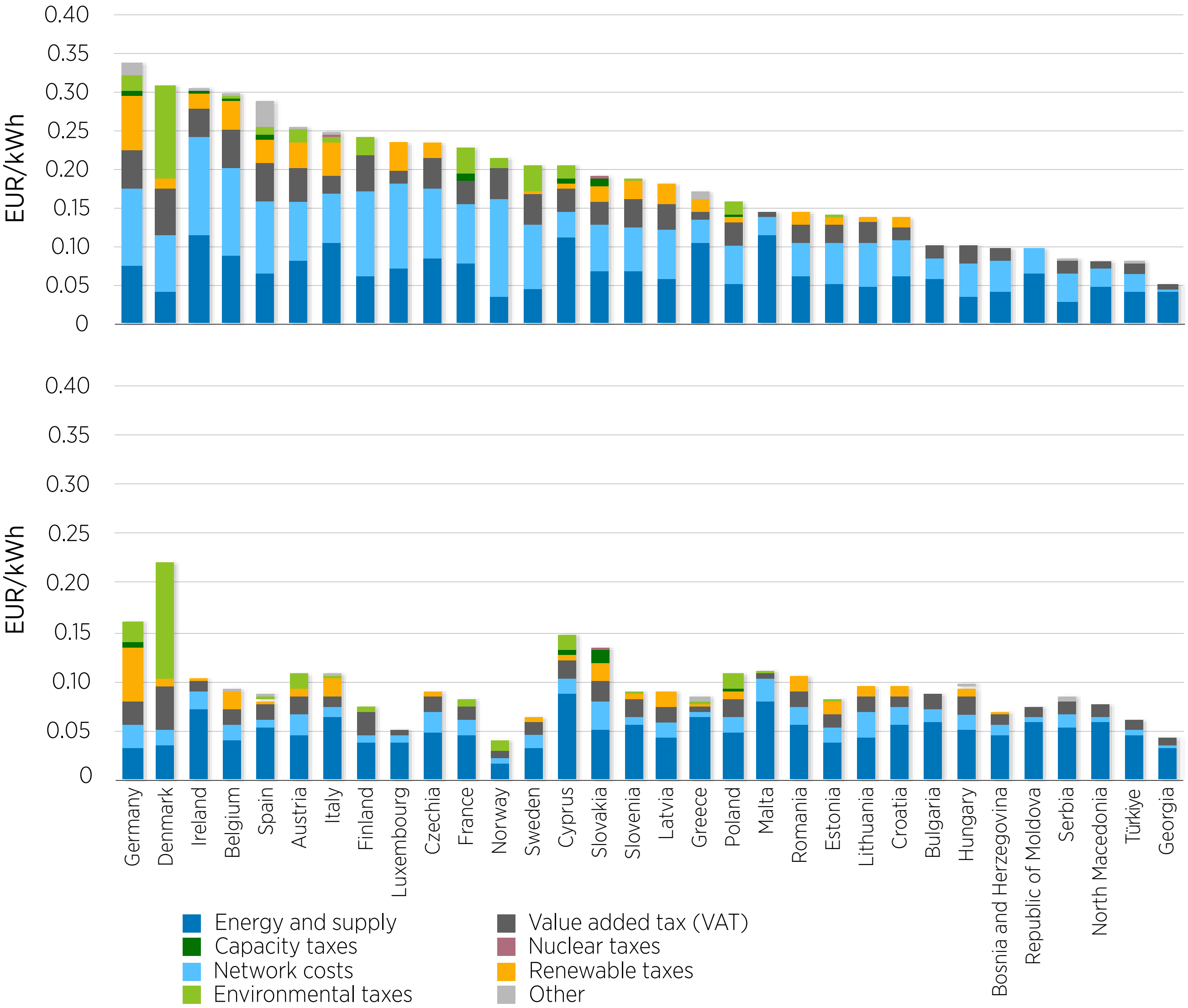
Generally, the retail of electricity is a deeply regulated activity, even where this part of the power system is liberalised. The final goal tends to be consumer protection, given the nature of electricity as a basic service.

In VIU models, users only have the option to buy power from the local utility or, sometimes, to become producers themselves with a distributed energy solution. Retail electricity prices are set based on recovering the operating and investment costs of the utility, including a rate of return. The final retail prices must be approved by the energy regulators, which prevent VIUs from overcharging users.

In liberalised systems, users can buy electricity from state-owned or private retailers of their choice, signing a contract with them. In any case strong elements of regulation persist. Transmission and distribution segments remain under the control of public entities, and have their costs recovered similarly to the VIU system, after informing the energy authority about their operation and invested costs, through a dedicated section of the electricity bill.

Figure 18 presents the structure of industrial and household electricity prices in different European countries in terms of energy, transmission and distribution, and tax components. The price structure varies greatly from country to country, including political decisions on the level of taxation allocated to electricity, voltage level connection and per-customer transaction costs. For example, in 2020, on average, industries consuming between 20 and 70 gigawatt-hours (GWh) per year saw an electricity price that was 45% of that applied to households (consuming between 1 and 2.5 MWh a year) in the EU-27 (Eurostat, 2022).

FIGURE 18. Average household (top) and industrial (bottom) electricity prices in selected European countries, 2020



Note: Household values refer to households with consumption from 1 MWh to 2.5 MWh per year. Industrial values refer to non-households with consumption from 20 000 MWh to 69 999 MWh per year.
Source: Eurostat, 2022.

The energy component in the electricity bill is usually low and often accounts for less than half of the final electricity price paid by end users (IRENA, 2017a). In liberalised retail markets, this component is set by energy retailers and can therefore change across different retailers. This and retail margins are the only parts of the electricity price not directly regulated in liberalised systems. However, energy authorities supervise these tariffs to ensure customer protection.

Finally, retail tariffs also include other regulated costs related to renewable energy support policies or social policies. These components can be very relevant in some countries.

3.4. SUPPORTING THE TRANSITION

Economic returns from current power system organisational structures were not enough to foster the initial deployment of renewable power plants. Support mechanisms were needed to introduce these technologies in the power system and to allow them to advance along learning curves. This situation was not new: since the origin of power systems, support mechanisms and dedicated policies have been adopted for different technologies deemed to be strategic.

From the early hydropower plants to today's mainstream fossil fuel plants (and notably nuclear power), all have received some form of direct and indirect support. By 2018, fossil fuels still received more than twice the subsidies of renewable energy or energy efficiency (IEA, 2019; Taylor, 2020).

For renewable energy, support policies range from **regulated payments** (described later); to research, development and deployment (RD&D) and policies for skill development; to industrial policies and system integration policies.[17] In the initial commercial stages, support came mainly in the form of subsidies for investment, and with time it evolved towards performance-related support in the form of feed-in tariffs or PPAs. Tax incentives have been conducive to kickstart and assist the deployment of renewable energy in many markets (*e.g.* the United States).

The overall driver to support renewable energy is based on the recognition of its social value (see section 4.1) and its importance in tackling climate change, in addition to energy security, independence and access. The higher investment costs, and until recently life-cycle costs, of most renewable technologies compared with incumbent technologies[18] required some form of support to incentivise investments and allow them to progress along learning curves.

Renewable energy technologies are capital intensive, which, together with uncertainties regarding performance, maintenance and supply chains during the first stages of their deployment, led to high risk perception by financial institutions, with the resulting increased cost of capital exacerbating the high cost barrier.

Support schemes for renewable technologies were initially conceived to push technologies along their learning curves: deploy the first megawatt so as to make possible reducing future costs with learning-by-doing, creating supply chains and training experts for these technologies. The policy instruments were meant to provide an incentive capable of overcoming the cost barrier, while creating a secure investment environment capable of attracting investors and reducing financing costs.

As support schemes were designed and implemented, the common consideration was that when achieving grid parity[19] (*i.e.* distributed generation achieving competitiveness with electricity retail prices) or market parity (*i.e.* competitiveness with electricity wholesale prices), support mechanisms would gradually be phased out (IEA, 2011). This concept still prevails today.

[17] IRENA, IEA and REN21 (2018) provided a new classification for a large number of policies for renewable energy.

[18] With the notable exception of large hydropower plants, which in any case received support in the past.

[19] Also referred to as "socket parity" or "plug parity".

Grid and market parity have already been achieved in many countries around the world (IRENA, 2021b), as attested by the record-low winning bid prices in recent auctions.

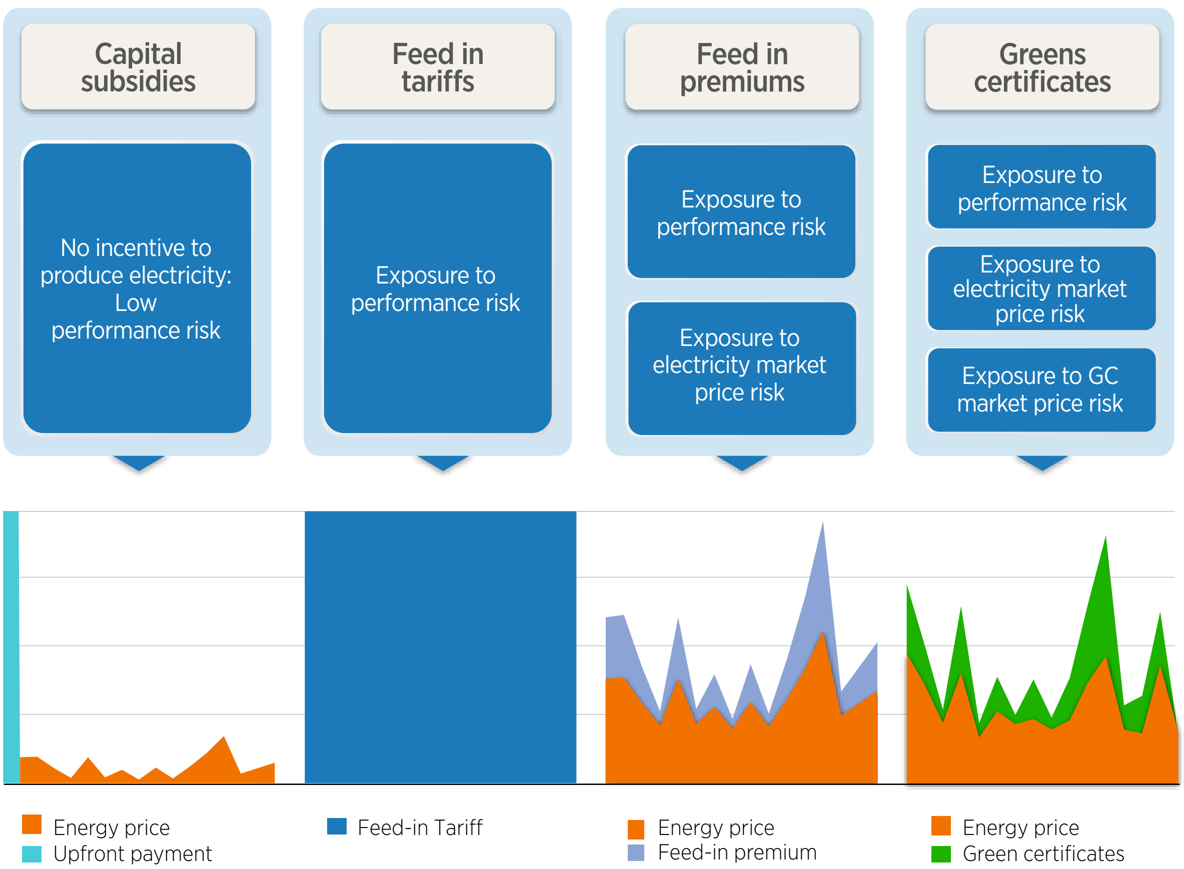
Still, the deployment of merchant power plants is far from becoming a common occurrence, and under current power system organisational structures it can never happen at the scale required by the energy transition. Chapter 4 presents the misalignments under existing power system organisational structures, which require maintaining additional regulated payments for renewables to become the mainstream in the power system. Chapter 6 discusses how organisational structures could evolve to become fit for renewable-based power systems, with the essentials of current additional regulated payments as the backbone.

Regulated payments for large-scale renewable energy

Capital subsidies were among the first instrument selected to encourage renewable energy deployment (Figure 19). These payments lower the overall investment costs and thus make the technology competitive or even attractive compared to other options, which allows for overcoming the increased risk perception. It is a relatively straightforward mechanism; however, once granted, it does not guarantee good operational performance.

Feed-in tariff schemes entail an agreed revenue per megawatt-hour produced. Feed-in tariff schemes are usually accompanied by priority of dispatch. Effectively, this means that electricity can be produced at any time of the day or year while receiving a stable payment, irrespective of the actual price of electricity or the value it brings to the power system. Under a feed-in tariff scheme, operators have to reach a minimum level of performance to repay the initial investment (the performance risk is transferred to the owners).

FIGURE 19. Regulated payments for renewable power generation



As renewable power technologies evolved further, support policies transferred the price risk to developers, who had to participate in electricity markets and would receive a **feed-in premium** – that is, an additional regulated payment on top of the market price. The premium definition differs across schemes, from a fixed value to variable (also called "sliding") premiums for each megawatt-hour sold into the market.

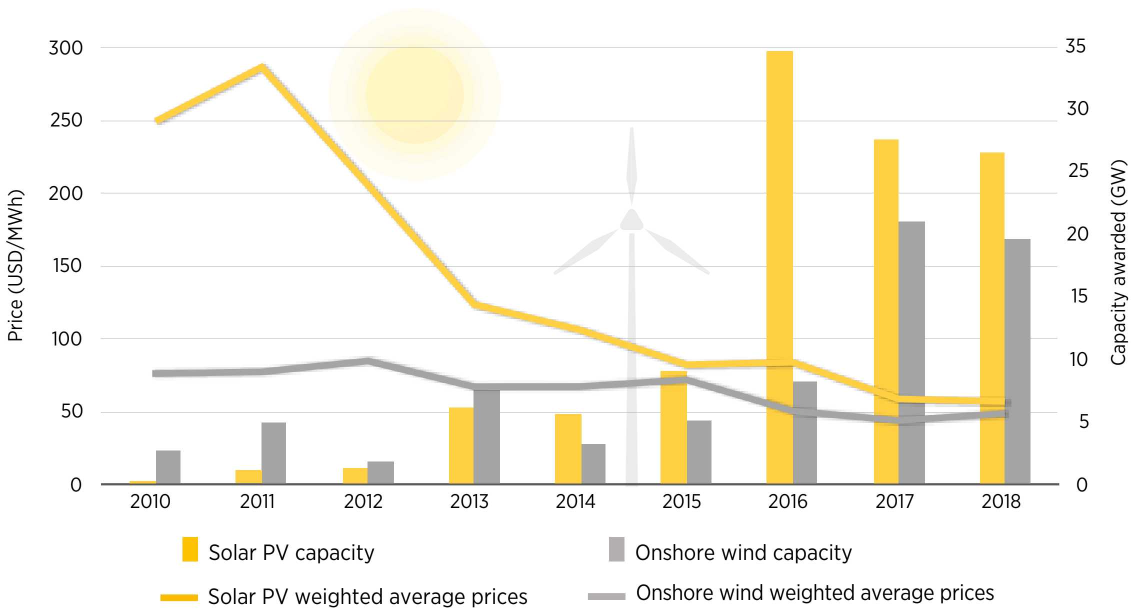
Similar to a feed-in premium, the green certificate systems allow generators to have another income stream for each megawatt-hour sold. Through the establishment of green certificates, a separated and regulated market for the renewable attribute of the generated electricity is set up by the regulator, who also sets a quota obligation (hence establishing a demand) and a floor price for the green certificates.

Rapidly reducing technology costs and asymmetry in cost structure information[20] led policy makers to consider auctions as a way to disclose the price of renewable electricity in their countries. Auctions are competitive schemes where winning bidders sign a PPA subject to the conditions imposed for each auction round. The payment takes the form of a feed-in tariff or of a feed-in premium.

Between 2014 and 2018, instruments for competitively set tariffs (PPAs) have gained popularity, owing chiefly to their ability to procure renewable-based electricity at the lowest price, or to achieve other political objectives, such as the creation of local supply chains or local employment.

By 2018, more than 100 countries had adopted auctions. Price results for solar and onshore wind auctions have decreased overall in the past decade (Figure 20). In 2018, solar energy was contracted at a global average price of almost USD 56/MWh, down from USD 250/MWh in 2010. Wind prices also fell during that period, albeit at a slower pace: from USD 75/MWh in 2010 to USD 48/MWh in 2018 (IRENA, 2019b).

FIGURE 20. Global weighted average prices resulting from auctions, 2010 to 2018, and capacity awarded each year



Source: IRENA, 2019b.

[20] Meaning that regulators do not have access to real technology costs and hence can introduce errors when fixing the additional regulated payments, for instance providing an incentive higher than the one needed to deploy the targeted capacity.

Support for distributed energy resources

Distributed energy resources – mostly rooftop solar PV – have benefited in some countries from support schemes similar to utility-scale plants (capital subsidies, feed-in tariffs and feed-in premiums). Cost declines, coupled with environmental and social benefits, have paved the way for grid-connected users to generate all or part of their electricity needs locally and to inject the surplus electricity into the grid. Specific regulations and policies could be adopted to support these distributed applications by facilitating their participation in the power system.

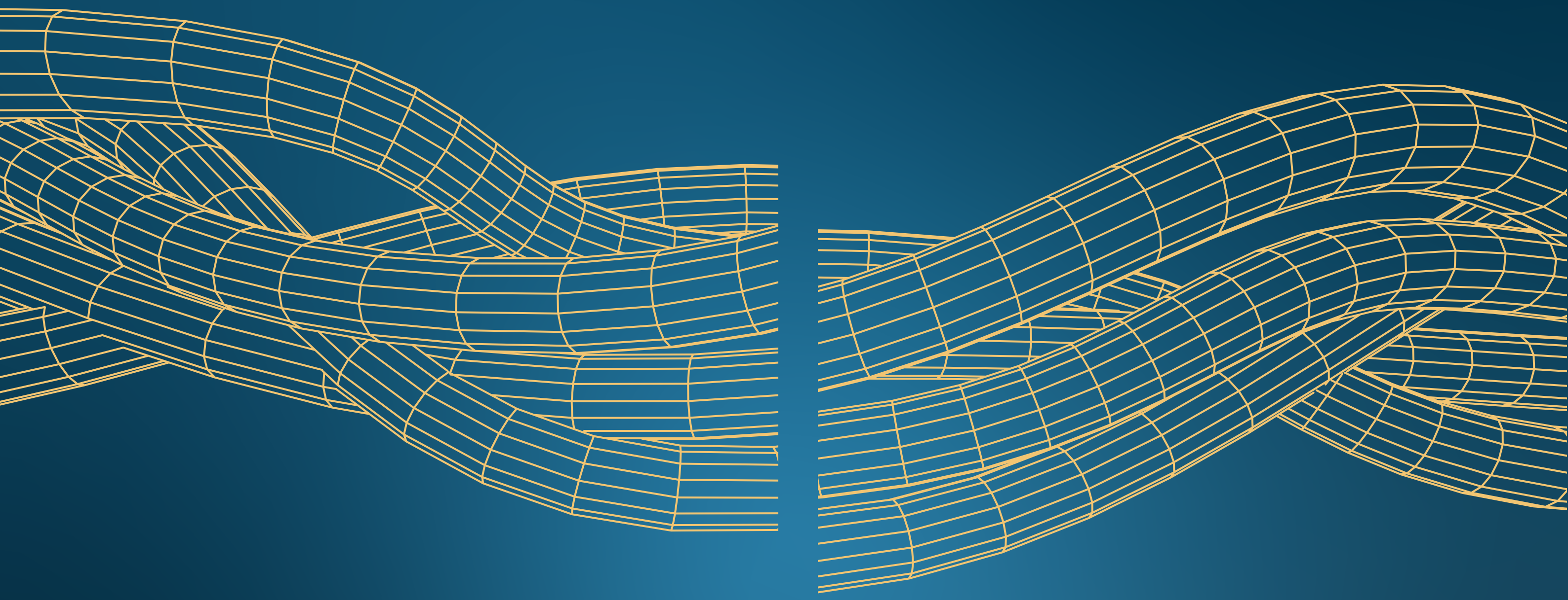
Net metering schemes allow users to use the distribution grid as a virtual storage for their electricity surplus. Net metering schemes allow owners of distributed energy resources to export the excess electricity (when the PV system is producing more than the building's consumption) to the grid, receiving a credit in kilowatt hours. The credit can be applied to offset consumption of electricity within a netting cycle (which can span from an hour to a year, depending on the jurisdiction). The PV system owner is billed only for net energy consumption. A short netting cycle (*e.g.* daily or hourly) implicitly pushes for more self-consumption by reducing the effective grid's virtual storage accessible to distributed energy resource operators.

In a net electricity billing scheme, a PV system owner can consume electricity produced by his or her plant or from the grid, as in the net metering scheme. However, credits for excess generated electricity are not granted in KWh terms, but all electricity injected is metered and credited at a predetermined sell rate that can be time-dependent or fixed.

Self-consumption of electricity generated from distributed energy resources can deliver benefits to both users and the system. However, careful planning and pricing need to be in place to avoid misalignments due to organisational structures not properly capturing the value of distributed energy resources for the power system and introducing conflicts between distributed and centralised assets or between pro-users and other users (IRENA, 2020c). Chapter 4 delves further in these issues.

PART 2

ENABLING THE TRANSITION OF POWER SYSTEM ORGANISATIONAL STRUCTURES



4 MISALIGNMENTS

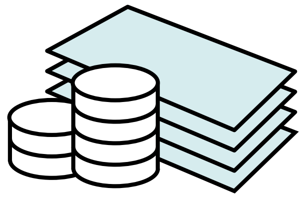
Power system organisational structures were designed with the blueprint of the fossil fuel era and had to be suited to the prevalent technologies of a centralised energy system and to the goals of the time. Governments now face a new challenge for the power sector: to successfully integrate renewable energy power plants at a rapid pace while maintaining adequate overall system costs and fostering the maximisation of both system and social value – and in a context of widespread electrification of the economy.

Most energy transition policies put in place have not deeply considered their interaction with prevalent power system organisational structures. In most cases, they were designed to bypass the existing power system structures in order to facilitate the deployment of renewable energy. As the transition progresses, misalignments between the current power system organisational structures, support mechanisms and the techno-economic characteristics of renewables become more apparent (IRENA, 2020b).

This chapter discusses misalignments that have different origins. Some are generated during the transition due to the interactions between renewable energy technologies and the prevalent power system structures (see sections 1.1 to 1.8). Others originate beyond the power system.

Energy systems were set up to provide energy services to the socio-economic system. In delivering those services through fossil fuels, however, they produced unwanted negative impacts on societies.

Marginal cost pricing structures are based on two assumptions:
the presence of positive marginal costs (fuel and opportunity costs) and dispatchability.
These conditions are not met by renewable-based power systems.



Misalignments such as climate change and air pollution can be partly addressed through the technological shift towards an integrated renewable-based energy system as pursued by the energy transition. But not all misalignments will be solved by this technology shift.

Misalignments specific to the power sector should be addressed by **redesigning the organisational structures** of power systems, since these misalignments originate in the interaction between current organisational structures and the characteristics of renewable technologies.

Some misalignments can remain unchanged or even be reinforced if patterns of behaviour from the past are maintained (or strengthened). Addressing these misalignments requires **incorporating other policies** beyond those pursuing the technological shift to renewables. This is the case, for instance, for the pursuit of social value, to address distributional issues, and to tackle the growth dependence of economic activity. Power system organisational structures can contribute their share in addressing these misalignments, but the challenge goes beyond their boundaries.

Addressing misalignments is a must to prevent barriers to transition. The next few sections discuss different misalignments, starting with those that exist mainly within the power system. These are followed by misalignments that, despite having clear impacts on the power system, reside mainly in outer systemic layers and that, to be addressed, require planning and policies reaching well beyond the power system.

4.1. MISALIGNMENTS WITHIN THE POWER SYSTEM

Advancing the energy transition under current power system organisational structures has required the implementation of support mechanisms for renewable energy generation. These support mechanisms were designed to bridge the gap between the actual costs of renewable generation and the cost recovered under the current organisational structures, at a time when renewable power was not cost-competitive against fossil fuels (due to technological immaturity and lack of incorporation of externalities) and represented a small share of the power system. Support mechanisms have also been put in place to stimulate investments in non-fossil-fuel flexibility technologies and other distributed energy resources.

While these support mechanisms have evolved to become more “system-friendly” over time, the fundamental disconnect between organisational structures and the specific techno-economic characteristics of renewables has not been addressed. The evidence of misalignments has triggered regulatory measures aimed at fixing them. However, by failing to address the bottom-line issues, these temporary fixes do not prevent misalignments from surfacing again as renewables deployment advances.

Depressed wholesale electricity prices

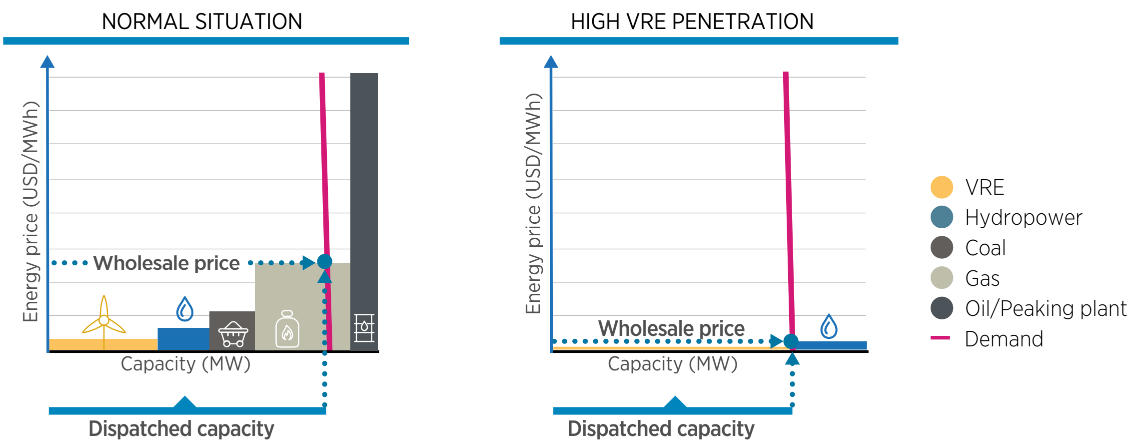
Marginal cost pricing structures are based on two assumptions: the presence of positive marginal costs (fuel and opportunity costs) and dispatchability. These conditions are not met by renewable-based power systems. One of the main aspects of a fossil fuel-based system is the presence of dispatchable power plants with sizeable operating costs (OPEX), mainly fuel costs, significantly contributing to the marginal costs. Most renewable energy technologies, in contrast, have very low OPEX (wind and sun are "free" resources), and VRE sources also have no opportunity costs as they are not dispatchable. Low OPEX and opportunity costs mean low marginal costs. Introducing very large shares of renewable energy and VRE makes current marginal cost-based organisational structures unable to sustain renewable-based power systems.

During the transition, due to marginal pricing, renewable energy generators displace conventional thermal generators in the merit-order curve. This leads to a reduction in the clearing price, thereby reducing the volume and price of electricity sold by conventional thermal generators (Figure 21) but also, importantly, reducing the "captured" price perceived by renewable energy generators. Such a situation – where the success in deploying renewable generation undermines its future viability because of wholesale price depletion – is often referred to as the "cannibalisation effect". This effect is magnified when electricity demand decreases, which during the transition may happen as a consequence of efficiency deployment.

Additional regulated payments exacerbate this issue by fostering further renewable generation deployment irrespective of the resulting wholesale price, since all or most revenue for these new generators flows through parallel mechanisms.[21] As a result, average energy prices are decreased and even negative wholesale prices would then appear.[22]

The wholesale price reduction introduced by increasing shares of renewable technologies, whether in liberalised or regulated[23] organisational structures, is often welcomed by policy makers (since it is, in the end, a reduction in energy prices). However, these low prices and the mechanism underpinning them introduce important transitional barriers as VRE shares increase.

FIGURE 21. Renewables penetration reduces wholesale prices under current marginal pricing allocation mechanisms



[21] In the limit, renewable energy generators getting part of their revenue from the wholesale market (feed-in premiums, green certificates) could even bid negative prices to access the extra revenue associated with their additional regulated payments. Negative wholesale prices could then result.

[22] Negative prices can also occur when inflexible power generators bid negative prices due to negative opportunity costs (*i.e.* it would cost more to shut down and restart a plant than paying for producing).

[23] In regulated procurement mechanisms based on marginal costs, the valuation of electricity is given by the last unit's marginal costs, as happens in wholesale markets. Hence, the "«missing money"» problem is conceptually present also in regulated systems.

Wholesale electricity markets are traditionally the main source of revenue for dispatchable generation. Price and volume depression can trigger requests and pressures to provide additional payments such as capacity payments to incumbent technologies (such as fossil gas), thus further entrenching them into the system and slowing down the transition.

The generators first and most affected by the deployment of renewables in marginal price allocation organisational structures are typically gas-fired power plants, which provide the bulk of current system flexibility. Fossil fuel-based generators have to be phased out during the transition. However, the 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.

The resulting low prices and low volumes (and in some cases fewer scarcity events[24]) as renewables are deployed in a power system relying on marginal pricing mechanisms are often referred to as the "missing money" problem, which refers to conditions where generators are unable to recover their investment.

On top of these barriers, the most fundamental issue is that today's organisational structures relying on marginal costs are unable to support a renewable-based power system once the additional regulated payments are phased out. The mainstream policy narrative argues that as renewables become cost-competitive, support through additional regulated payments should be retired. However, once the revenue for VRE power plants is limited only to that from marginal pricing structures, the extremely low wholesale electricity prices that result from high penetration of renewables compromise the very business case for these plants. This, in turn, leads to an increased risk perception that directly translates into higher capital costs, hence preventing renewable generation from delivering its potential for low-cost electricity.

Offshore wind farm, Freepik

[24] In some cases, the regulated payment schemes worsened overcapacity situations. This overcapacity reduced or eliminated the occurrence of scarcity events. For example, scarcity events never occurred in Germany in 2014 (Hu *et al.*, 2018).

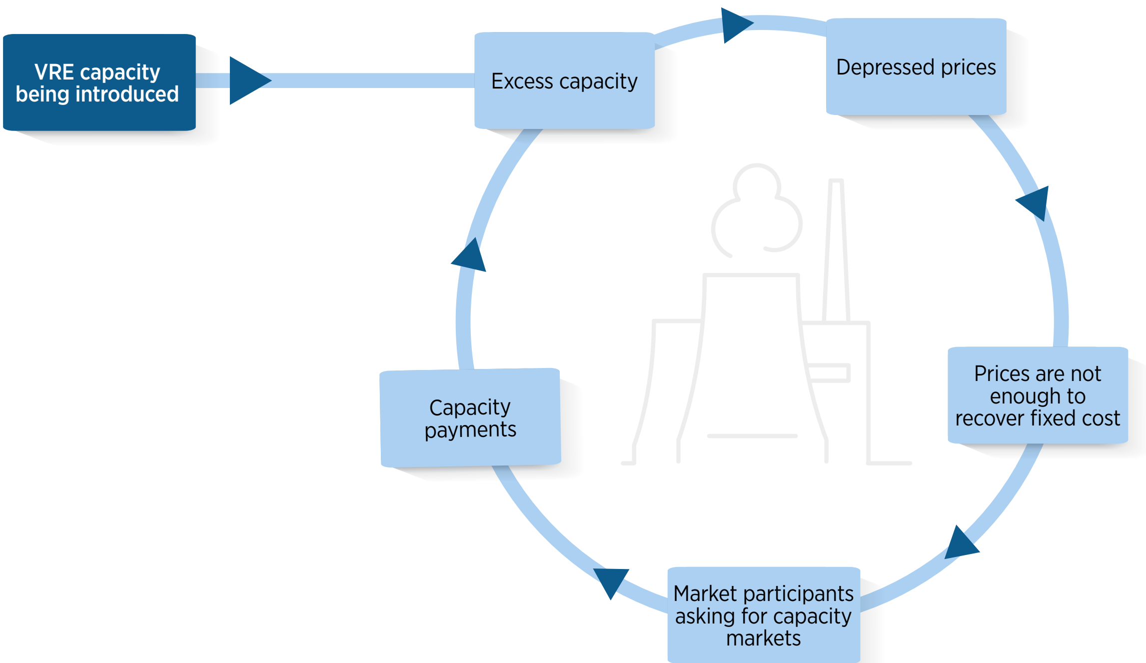
Capacity remuneration mechanisms for fossil fuel plants: The lock-in effect

The prospected low revenue streams associated with the "missing money" problem discourage investments in new dispatchable capacity or even keeping existing capacity online (Hu *et al.*, 2018). Reduced dispatchable capacity while other flexibility elements have not been fully incorporated in the power system would put at risk system adequacy. To solve this, many countries have turned to capacity remuneration mechanisms[25] (chapter 3).

The use of capacity procurement systems to make up the "missing money" needed to support the required capacity creates distortions and potential barriers to transition (Bushnell, Flagg and Mansur, 2017; Harvey, Hogan and Pope, 2013; Muñoz, 2019). Capacity mechanisms, in fact, create a perverse feedback (Figure 22):

- Increasing VRE generation leads to a reduced average price of electricity in marginal-based organisational structures.
- Remuneration is not enough to recover the investment costs of generation assets or to encourage new investments.
- To fill the revenue gap, additional regulated capacity payments are provided to existing, dispatchable, centralised and mostly fossil fuel power plants.[26] The fossil fuel plants receiving today's capacity payments become entrenched in the power system, slowing their phase-out and the deployment of new flexibility sources suited for a renewable-based power system. The economic resources used for today's capacity payments crowd out those needed to deploy new flexibility or renewable resources in the system.

FIGURE 22. The capacity payments feedback loop



Source: Adapted from Muñoz, 2019.

[25] Capacity payments are explicit in liberalised systems but often implicit in regulated systems, where the economic resources to recover the costs (or face the finance obligations) linked to underutilised plants are collected from the balance sheets of vertically integrated utilities or from additional taxation.

[26] A notable exception was Mexico (IRENA, 2019b), where auctions for capacity were open to all technologies.

The result of this dynamic is locking in fossil fuel plants, hence delaying the introduction of flexibility elements capable of supporting a renewable-based power system.

Capacity remuneration mechanisms, if deemed necessary for supporting flexibility investments to maintain system reliability, should be designed recognising the system and social value from all flexibility resources (on both the supply and demand sides), within a transition context and within the framework of an organisational structure fit for a renewable-based power system. Both supply-side and demand-side resources (batteries, aggregators, electric vehicles, etc.) give a large array of options for system operators to maintain system reliability without centralised power plants (IRENA, 2019c) (see chapter 6).

Inappropriate ancillary system services

System operators procure different types of ancillary services. In some cases, ancillary services provision is a mandatory requirement to participate in the power system, while in some liberalised systems, these services are procured through dedicated ancillary services markets.

In any case the regulations for providing ancillary services and the definition of the services to be procured were designed in the era of fossil fuels and centralised generation.

As a result, these services are still procured in many cases from specific generation units – from fossil fuel generators and hydropower plants. This does not allow the space for procuring these services from all the stakeholders that could provide them, which, beyond hydropower and pumped storage, include dispatchable renewable generators, battery storage, demand-side response and VRE (Figure 23).

FIGURE 23. Grid services and technologies

	Fossil fuel power plant	Dispatchable renewable energy	VRE	DSM	Battery
Frequency control	●	●	◐	◐	●
Voltage control	●	●	◐	○	●
System management	●	●	◐	◐	●
System restoration	●	●	○	○	◕

● Capable ◐ Capable with limitation ○ Not capable

Note: DSM = demand-side management; dispatchable renewable energy = hydro, geothermal, biomass and CSP power plants.
Source: RGI, 2020.

The characteristics of ancillary services need to evolve to meet the requirements of renewable-based power systems. As VRE becomes a larger portion of electricity supply, its impacts on the functioning of the power system will also increase. Already today, with the current share of VRE, it is possible to observe significant impacts on the system operation created by wind and solar PV. To have high levels of security, adequacy and service quality, while avoiding excessive costs for society, the technical challenges created by increased VRE shares need to be properly addressed, which may require different types of ancillary services.

VRE power plants usually interface with the network through power electronics, and hence do not provide rotating inertia and reactive power by default, unlike traditional thermal and hydro generation. Therefore, VRE power plants do not have the inherent capability[27] to support frequency and voltage that traditional power generation plants had.

There are, however, options to address the challenges posed by an increasing share of VRE, which can be procured from the technologies involved in renewable-based power systems.

VRE sources are capable of participating in the existing ancillary service markets when enabled to do so. For example, wind power generators are allowed to provide balancing services in most of Europe (IRENA, 2019c), while in Chile, solar PV power plants have been tested to provide ancillary services to the utility grid and to ensure grid stability: in 2020 the first PV plant was licenced to supply ancillary services (First Solar, 2020).

Additionally, VRE power plants are becoming responsible for their own imbalance in the grid. In different EU Member States, wind turbine operators face charges for incorrect forecasts, the same way as conventional generators (IRENA, 2019c). Battery storage is already allowed to provide ancillary services in many different power systems, for example in the PJM system in the United States and in Australia, Ireland and many EU markets (EirGrid, 2020; Energy Victoria, 2021; IRENA, 2019c; PJM, 2020).

At the same time, new ancillary service products have been designed for VRE integration such as enhanced frequency response in the United Kingdom and ramping products in California (CAISO, 2018; National Grid, 2019).

Electricity bills and their conceptual disconnect with renewable energy costs and remuneration

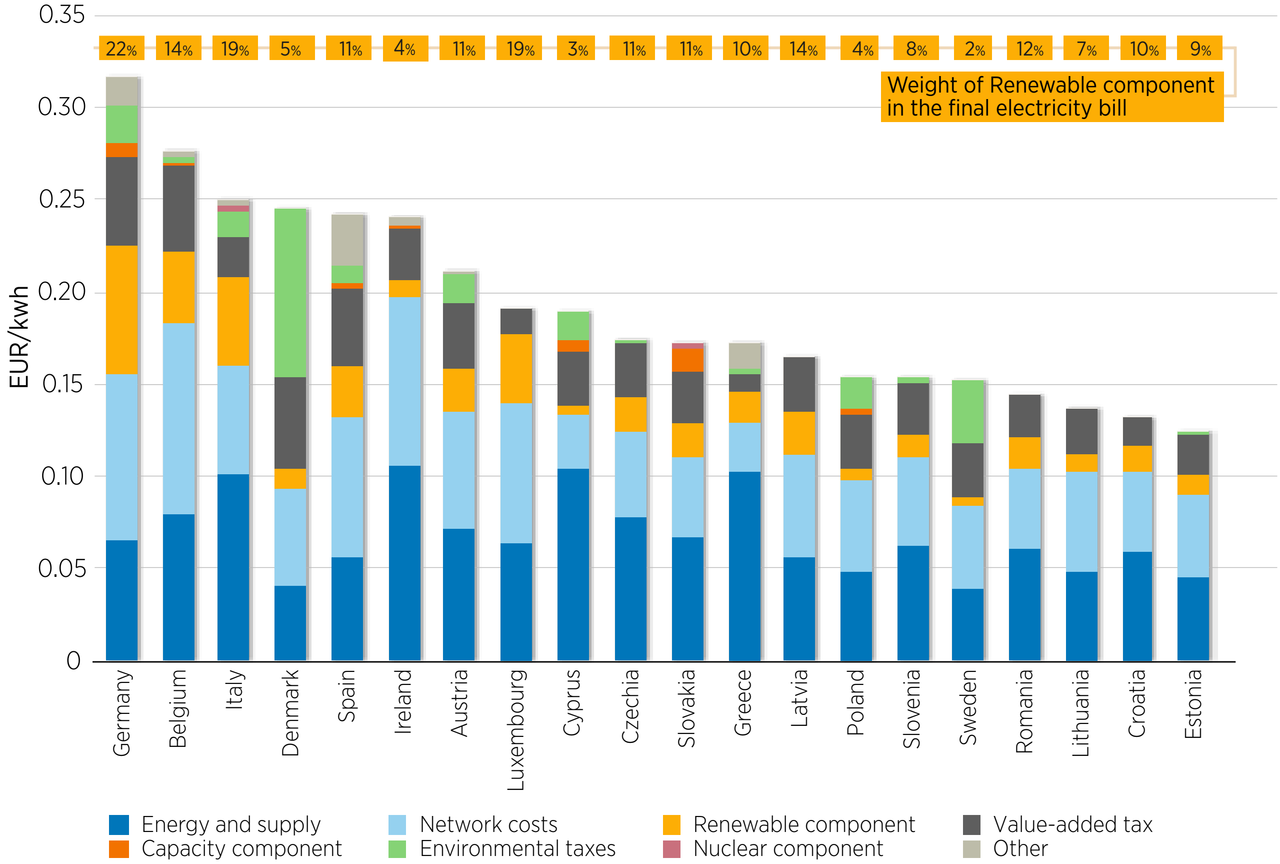
Ultimately, economic resources for all power system payments are collected through the bills passed to end users, sometimes complemented by targeted/general taxation. Therefore, electricity bills incorporate different components, the main ones being the energy and network cost components. In addition, specific components are added to cover the costs of other services. Additional regulated payments for renewables are usually covered by a renewable energy component, as in European liberalised systems (Figure 24).

The framing of payments for renewable electricity generation as a component separated from the bill's energy component hides many nuances and can lead to wrong perceptions. Indeed, as the penetration of renewables increases, and as auctions begin to procure renewable projects with levelised costs of electricity (LCOEs) below the average energy component, the current structure of the electricity bill results in a lowered energy component (renewables depressing the marginal price) and an increase in the renewable component (more volume of renewables receiving additional regulated payments, although at decreasing unitary costs). The result can be an increased perception (for both policy makers and end users) of "expensive" renewable energy, potentially triggering barriers to further renewables deployment, whereas the reality is the opposite (Agora, 2018).

This billing structure can produce the wrong impression to end users that they are paying for the cost of electricity in the energy component, while the additional regulated payments for renewables subsidise the deployment of renewable power plants. In turn, this can trigger the thinking and expectation that renewable components are bound to disappear as soon as renewables become competitive, and since renewables are in many cases reaching this competitiveness, political momentum is already building up to phase out these payments.

[27] However, through additional layers of power electronics, VRE can contribute to both frequency and voltage control.

FIGURE 24. Average household electricity bills by component in selected European countries, 2020



Source: Eurostat, 2022.

This misunderstanding would produce unsurmountable barriers to transition because, as discussed earlier, the wholesale marginal pricing mechanism is not appropriate to support a power system based on renewables.

Electricity billing also plays an important communication role. Hence its structure needs to be updated to clearly communicate the meaning and implications of each component to end users, as well as aligning it with the characteristics of a renewable-based power system (IRENA, 2019c) (see chapter 6).

The "grid death spiral"

Schemes for small-scale distributed renewable energy sources (currently mainly solar PV[28]) differ from those for utility-scale power plants in many factors, from permitting procedures to remuneration, with the goal of supporting the deployment of these installations with very different characteristics. Distributed generation may provide additional system and social value such as minimising losses, reducing grid expansion requirements and increasing citizens' involvement in the transition. One option to support distributed generation while reducing the burden on distribution grids is encouraging self-consumption (such as net billing schemes). Self-consumption, in turn, reduces the total volume of billable electricity.

To guarantee system costs recovery, electricity bills capture all system costs in most jurisdictions. Some of these costs are related to renewable energy deployment. Grid and other system costs are also

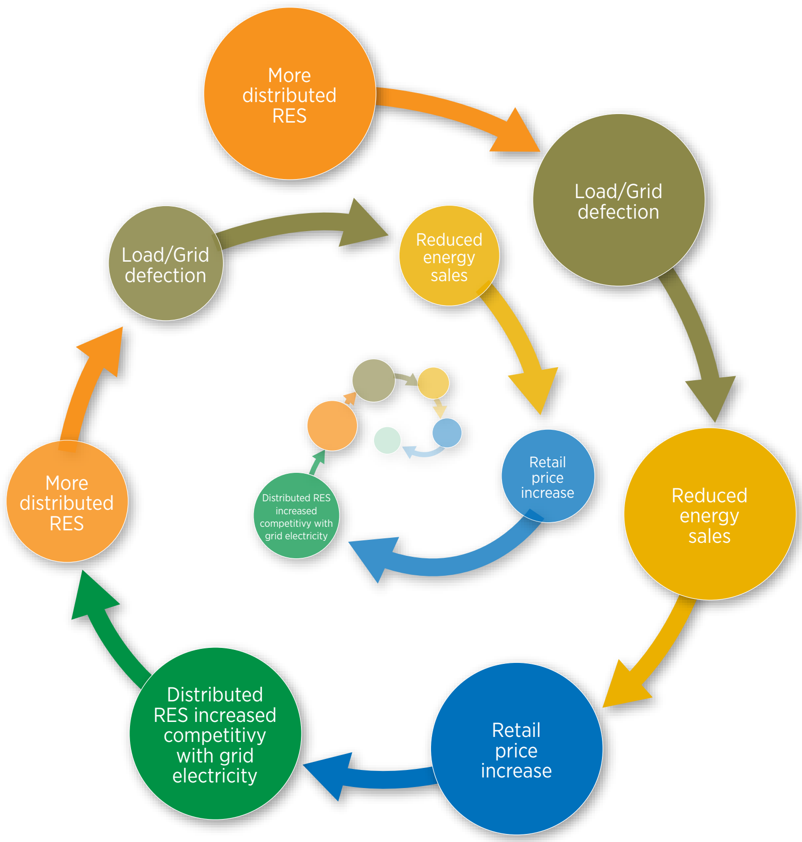
[28] Either in households, businesses or industry.

included in the electricity bill, and the increase in distributed resources may impact them through, for instance, distribution grid upgrades, remote monitoring and control capabilities, and other investments needed to manage short-term variations of VRE and reverse flows (IRENA, 2019c; Joskow, 2019).

The cost of electricity perceived by end users is the overall price in the electricity bill, which is significantly higher than wholesale electricity prices because it includes all other power system costs. End users compare the costs of distributed renewable generation (which are higher than utility-scale renewable generation) with the resulting overall billed electricity price, and often are not aware of the full range of services provided by the grid (beyond the sold electricity). Some support mechanisms for distributed renewables such as net billing reinforce this perception.

As self-consumption increases, for a given overall demand, less electricity has to be generated, distributed and billed by the central system, which, under prevailing tariff structures and grid remuneration mechanisms[29], results in a smaller basis for the recovery of the fixed costs of the grid. Hence electricity tariffs need to be increased,[30] starting a vicious cycle: rising electricity bills encourage more investment in self-consumption solutions such as solar PV (load defection), which cause further reductions in the volume of electricity billed, which further increase electricity tariffs, pushing for more distributed PV, and so on. This eventually leads to grid defection,[31] where the potential value from the grid would be lost. This situation is called the "grid death spiral" (Figure 25).

FIGURE 25. The grid death spiral



[29] Where the operators of distribution and transmission systems recover a big part of their fixed costs mostly on the basis of the volume of electricity delivered.

[30] Often both the energy and system cost components, if there is no neat mapping between cost components and billing concepts.

[31] Once a user fully defects from the grid, it stops receiving any service from the grid, and hence needs to cope on its own with all the requirements for a reliable and secure supply, which among other things requires incorporating significant amounts of electricity storage.

The grid death spiral issue goes beyond the fact of losing or not losing the potential system value of the grid for those users that defect. There is a social justice dimension attached to it.

Given their capital-intensive nature, distributed renewable energy sources, such as solar PV systems,[32] have usually been adopted first by higher-income households. Vulnerable, low-income users cannot afford the initial investment, even if a tax incentive or a regulated payment scheme is in place (Barbose *et al.*, 2018; Coffman, Allen and Wee, 2018; Gaigalis *et al.*, 2016, Lukanov and Krieger, 2019; Macintosh and Wilkinson, 2011).

Hence, the grid death spiral dynamic can exacerbate energy poverty, as the increased electricity bills burden users that are fully dependent on the grid but have not been able to invest in distributed energy resource solutions, such as low-income users. This reduces even further their opportunity to deploy renewable energy and increases social inequalities. These social inequalities can trigger barriers to transition as a consequence of not bringing all on board by failing to address the equity dimension of the energy transition.

Hence policy making should pay special attention to the social dimension of self-consumption schemes, and tailor measures so that their benefits can be equitably shared. Favouring self-consumption in areas where energy poverty is more persistent may be a solution (Bouzarovski, 2018), as well as directly addressing the regressive impacts of support schemes for distributed renewables (see also chapter 5 for collaborative solutions beyond regulation and competition).

A suitable redesign of organisational structures that recognises both the value and the costs of distributed energy resources for the power system and for society would make it possible to benefit from the widespread adoption of distributed energy resources and increasing participation of all users (Bronski *et al.*, 2015; IRENA, 2019c; Lo *et al.*, 2019). A case in point about how to advance in capturing the system value and some components of social value in distributed generation support schemes is the feed-in tariff design of the State of Victoria in Australia (Box 13).

Box 13. Aligning price and value for distributed generation

In the State of Victoria, Australia, the energy authority Essential Services Commission (ESC) conducted an extensive study in 2020 to understand the "true value" of distributed solar PV generation in terms of grid investment, transmission loss avoidance, avoided energy generation, costs of ancillary services and the avoided social cost of carbon emissions.

The ESC also recognised that feed-in tariff arrangements historically did not provide compensation to distributed generation customers for the environmental and social value that distributed generation provides. This resulted in distributed generation customers being under-compensated for the external benefits that their systems created.

The ESC recommended and later introduced multiple feed-in tariff levels based on the time and location of export. It recommended that the feed-in tariff should align with time blocks of retail prices (i.e. peak, shoulder and off-peak). Rate levels change every year.

Source: Energy Victoria, 2020.

[32] Which for full defection or even higher self-consumption shares need to be complemented with batteries, and hence are even more expensive.

Cost, price and value

Although this section addresses the cost, price and value misalignments mainly from a power sector perspective, these misalignments have strong links with outer systemic layers (economy, society), and hence are midway between this section and the following one, which addresses misalignments beyond the power system.

Discussions about how to allocate value and hence about how value relates to prices and costs are almost as old as economic thought, and under the current transition context they become extremely relevant to diagnose structural misalignments and to steer our socio-economic system towards prosperity (Mazzucato, 2019).

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 and advancing the transition. The power system structure should aim at aligning the value and price of the produced electricity within the power system,[33] while providing mechanisms for appropriate cost recovery. Box 14 provides a description of what is included in the cost, price and value dimensions 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 compression). Usually, however, this focuses only on the total amount paid to producers per megawatt-hour, irrespective of system costs and externalities.

The price compression goal is not new from the energy transition, as it has been extensively applied in the past. At the onset of the energy transition, price compression has been the main driver behind the expanded use of auctions.

However, as the transition advances it becomes increasingly evident that a systemic approach is needed to address the multiple challenges overlooked by price compression approaches, which often fail to capture the value for the power system of the newly procured generation.[34] And beyond that, the wider social value of renewable-based generation also escapes price compression considerations. [35]

The lack of appropriate time and location pricing signals and the associated misalignment between price and system value 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 (Liebreich, 2017). 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.

[33] 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.

[34] Notably, price compression can also, mainly in liberalised contexts, play in an opposite direction to efficiency deployment due to rebound effects.

[35] Examples of how the lack of recognition of social value brings additional costs or lower benefits to the society are presented in IRENA (2020c).

Box 14. The cost, price and value dimensions of electricity

One of the aspects often entangling discussions about cost, price and value is failing to understand what each of these concepts includes, because they are more nuanced than may first appear. This box presents a brief conceptual description of what each of these terms includes in the power sector context:

Cost

Two components are included within the cost dimension: **levelised** cost of electricity (LCOE) and (negative) externalities.

The cost dimension also includes both **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 aimed at 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

Overall *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. From a conceptual perspective, two main elements can be distinguished within the price: 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.

Hence the price dimension includes three distinct components – **market prices, additional regulated payments and subsidies:**

- 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".
- *Additional regulated payments* are price complements** introduced to correct identified flaws in the implemented pricing structure. For mature transition-related technologies, feed-in tariffs and auctioned PPAs are additional regulated payments to overcome the unsuitability of the current power system structures to accommodate renewable-based power systems.
- *Subsidies* are price complements made to support a given power generation technology. The motivation for granting a subsidy can vary and is based on specific policy goals, from inducing technology learning and driving down the costs of new technologies, to creating new economic activity and jobs (Taylor, 2020). Several differentiations come into play: —*Direct versus 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. Indirect subsidies are the difference between post-tax and pre-tax subsidies as per the

International Monetary Fund (IMF, 2015a).

—*Subsidies that reward social value versus 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:*

- *Power system value* is associated with how, when and where electricity is produced. Each power plant, be it renewable or not, may bring additional system costs (new grid lines, additional operating reserves, storage or other flexibility requirements, etc.). These in turn can be minimised by proper technology and design choice. The higher the system value of the generated electricity, the lower the additional system costs it induces.
- *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 contribution of the energy transition to the democratisation of the energy system can have significant effects on the social value of the produced electricity (Burke and Stephens, 2018).

Attempts are being made to incorporate power system value into policy making, energy planning and energy procurement through, for example, value-based auctions (IRENA, 2019b; Villareal, 2018). 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 (Anderson *et al.*, 2018; Denholm *et al.*, 2015; IEA, 2018; Jorgenson *et al.*, 2013; Milligan *et al.*, 2017). The value-adjusted LCOE introduced in IEA (2018) 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 report differs from that used in IEA (2018). Instead of lumping cost and value elements into a single parameter that represents neither cost nor value, this report retains the conceptual differentiation between the cost and value dimensions with the aim of properly informing the discussion. This report 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.

* Herewith we focus on power system organisational structures, but externalities are not at all the preserve of power systems, and they may arise in virtually all economic activities.

** These price complements can become the only payment (like in feed-in tariff schemes) or remain a complement to the wholesale price (like in feed-in premium schemes).

*** Although in specific local contexts fossil fuel subsidies may have added social value (rural energy access, energy poverty eradication, etc.), in a transition context they cannot be considered to add this value in the medium to long term, and they crowd out the resources needed to provide social value and address the transition in these contexts.

Additional regulated payments such as feed-in tariffs and PPAs, when irrespective of the location and timing of electricity generation, implicitly push developers to find locations where resources are abundant and to adopt plant designs that minimise costs and maximise generation. This drives down the market price of electricity, 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.

As system integration costs become apparent, policy makers across the world begin to adopt strategies aimed at reducing them by introducing mechanisms to select the projects with higher system value, even if this does not lead to "pure" cost compression (IRENA, 2019b). An example comes from Brazil, where auctions select renewable projects considering their impact on the power system (Box 15).

Box 15. A RE-alignment: Incorporating cost-benefit evaluations into the selection process, Brazil

For certain technologies in Brazilian energy auctions, winners are selected on the basis of a cost-benefit index and not on the basis of price alone.

The reasoning behind the index is to incorporate, for bid comparison purposes, an expected value of the renewable electricity based on its geographical location, hourly profile and seasonal profile. The expected value of the generated electricity for the power system is evaluated through its expected market price, known as the CEC (custo esperado de compra). The CEC is the second most important item (after the auction bid price) in determining the index ranking of a renewable power plant.

The CEC is defined as the expected value of spot market settlements over the plant's useful life. It is determined through a simulation in which the system planner attempts to differentiate renewable generators at different locations and with different production profiles. The CEC is calculated for each plant based on its certified production profile. Here, complementarity plays an important role. For instance, wind generators located in Brazil's north-east region complement the country's abundant hydropower, as their output typically increases during the dry season. Plants with more pronounced complementarity get higher CEC.

Policies favouring rapid deployment of renewable energy have at times side-stepped the social dimension (Box 16). In particular, competitively set mechanisms like auctions may facilitate the cost compression objective, but their outcomes may be less than optimal from other socio-economic perspectives (IRENA, 2019b). For example, they may not produce a diversified landscape of actors or generate the shared benefits envisioned for a just and inclusive transition (Fell, 2017; Jacobs *et al.*, 2020).

However, recognition of the socio-economic benefits is becoming more common in renewable energy policies. Auctions, for example, are being implemented in some jurisdictions with mechanisms to facilitate the participation of small players (Japan) or community-owned projects (Australia, Germany), or to value projects that create jobs for people from diversified socio-economic or ethnic backgrounds (South Africa) (IRENA, 2019b).

The distinction between subsidies and additional regulated payments warrants further discussion, because lack of clarity on this point leads to important policy and planning misalignments potentially hindering the transition of power system organisational structures.

Often, under the term "subsidies", fundamentally different elements are lumped together. 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.

Box 16. Lack of recognition of the social and environmental value of energy

Private and public entities and investors all play a role in accelerating the transition to a low-carbon economy. Capturing the value of a just and fair transition beyond the return on investment should be a cornerstone of the energy transition.

Renewable energy deployment is not immune to some of the negative impacts of fossil fuels and nuclear energy deployment, particularly if it follows the same paradigms that guided the development of the power systems of the fossil fuel era. Indeed, renewable energy deployment can also result in human and environmental rights violations and externalisation of costs to communities and nature.

Negative impacts are driven by a lack of recognition of the social and environmental value of energy developments. They include the execution of projects without the due informed consent of affected communities, the lack of measures to mitigate the power imbalance in the dialogue between communities and promoters (either private or public), the priority access to electricity for industry and urban areas as opposed to rural population, land grabbing, dangerous working conditions and precarious wages across all the value chain, as well as damage to the life and livelihoods of indigenous peoples (350 Africa.org and WoMin, 2020; Business & Human Rights Resource Centre, 2020; Finley-Brook and Thomas, 2011).

In the last decade (2010-2019), almost 200 cases of human rights violations have been reported linked to renewable energy utility-scale projects, 61% of them in the Latin American region. The development of utility-scale renewable energy projects was the fourth sector that most-violated human rights in 2019, after mining, intensive agriculture and waste disposal (Business & Human Rights Resource Centre, 2020; Global Witness, 2019). Historically, allegations of human rights violations in the renewable energy sector tended to be related to hydropower developments. But as the transition unfolds, allegations have been made across all sub-sectors of renewable energy deployment such as wind, solar, bioenergy, geothermal and hydropower, where weak standards to protect workers and communities are in place.

Host communities' true participation from the design stage of projects is essential to align the project with community needs and to produce social value, allowing communities to benefit from the project. However, prevalent organisational structures do not foster meaningful social involvement. The social fracture induced by the aforementioned violations and limitations represents a barrier to engage host communities in the pursuit of the energy transition. Even worse, it often triggers a resistance to what is locally perceived as an unsustainable transformation.

* Increasingly linked to transition-related technologies.

This becomes evident when proposals for power system structure reform, such as the approach discussed in chapter 6, take the conceptual framework of current feed-in tariffs or PPAs and turn it into one of the pillars of an organisational structure fit for renewable-based power systems.

If a technology needs additional support because of the market price not covering its costs, this can be addressed through an additional regulated payment or a subsidy that covers the difference between the market price and the technology's cost. But this should always be conditional on the social value from this technology. Subsidies for technologies with high external costs should be phased out (*i.e.* fossil fuel subsidies, see Box 17), and in any case hidden subsidies (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. 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. Feed-in tariffs and PPAs can be understood as additional regulated payments to overcome the unsuitability of the current power system structures to accommodate renewable-based power systems, although feed-in tariffs and PPAs may also include elements of subsidy 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 cost, price and value misalignments can play out in the power sector in various ways. The price misalignment in wholesale electricity markets was discussed in section 4.1. However, fully understanding the space of misalignments requires simultaneously considering the three dimensions of cost, price and value, since the realm of misalignments goes far beyond the part of the price dimension allocated by marginal pricing mechanisms.

Organisational structures play an important role in determining how the cost, price and value dynamics unfold. Figure 26 presents three examples of fossil fuel and renewable plants operating under different organisational structures to illustrate these potential misalignments between the three dimensions.

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

For a fossil fuel power generation plant operating under current organisational structures (Case 1), additional regulated payments and subsidies can be very high, even higher than those for renewable generation. The "missing money" problem discussed earlier is likely to lead to additional regulated payments such as those from capacity remuneration mechanisms. But above all, huge indirect subsidies due to the plant's externalities not being internalised are in place. Yet the plant's overall value may be significantly lower than electricity prices and costs.

Cases 2 and 3 correspond to renewable power generation plants operating under the current power system structure (Case 2) and under a power system structure fit for renewable energy technologies (Case 3), such as that discussed in chapter 6. Because of the technologies involved, Case 2 has lower costs than Case 3, but the value for the power system of the generated electricity is also lower in

Box 17. Fossil fuel subsidies

Fossil fuel subsidies* are still abundant worldwide despite the fact that they are a barrier to the decarbonisation of economies. However, thanks to climate and welfare considerations, debates about fossil fuel subsidy reforms are gaining ground.

When undertaking subsidy reform, it should be remembered that governments historically established fossil fuel subsidies for a variety of reasons, including to reduce poverty. Therefore, addressing distributional issues in subsidy reforms is essential to avoid unintended barriers to the energy transition.

Phasing out fossil fuel subsidies provides room for improvement in economic, environmental and social prosperity, opening up governments' budgetary space for investments in the energy transition and social welfare, while helping to reduce fossil fuel lock-in effects. But to reap these benefits, regressive effects must be avoided. Although there is no wide social awareness of it, today's fossil fuel subsidies are regressive, with the wealthiest benefiting the most. Globally, the richest 20% of households capture more than six times the benefit of fuel subsidies as compared to the poorest 20% (IMF, 2015b; UNEP and IISD, 2019).

Nonetheless, phasing out fossil fuels can produce negative short- and long-term distributional effects such as a disproportionate burden on lower-income groups, reduced energy access or major labour loss, reduced competitiveness, substitution with unsafe, more polluting fuels, and poor accountability over price transparency (Bridle *et al.*, 2018; Rentschler and Bazilian, 2016). Preventing these negative impacts requires holistically addressing these effects and fostering social engagement.

For instance, eliminating fossil fuel subsidies on consumption frees considerable government economic resources, but in the absence of a holistic approach that clearly allocates these resources to improve welfare and the situation of vulnerable households, explicitly addressing the regressive impacts of exposing vulnerable groups to increased prices (affecting their ability to cook, heat or commute), social opposition can be expected to block effective reform.

In the absence of such a holistic approach to fossil fuel reform, barriers can be expected in response to changes in international fuel prices. In 2019, some countries already started pushing back their subsidies reform schedules in response to high international fossil fuel prices. For instance, Indonesia and Malaysia committed to subsidise energy prices, while India reduced the excise duty on petrol and diesel, and Brazil increased its subsidy on diesel (Matsumura and Adam, 2018).

Therefore, a holistic approach to fossil fuel reform is a must. Failing to explicitly and satisfactorily address the social consequences of fossil fuel phase-out (with special emphasis on distributive impacts) results in increasing social resistance, especially in a context of foreseeable volatile fossil fuel prices (Beaton *et al.*, 2013).

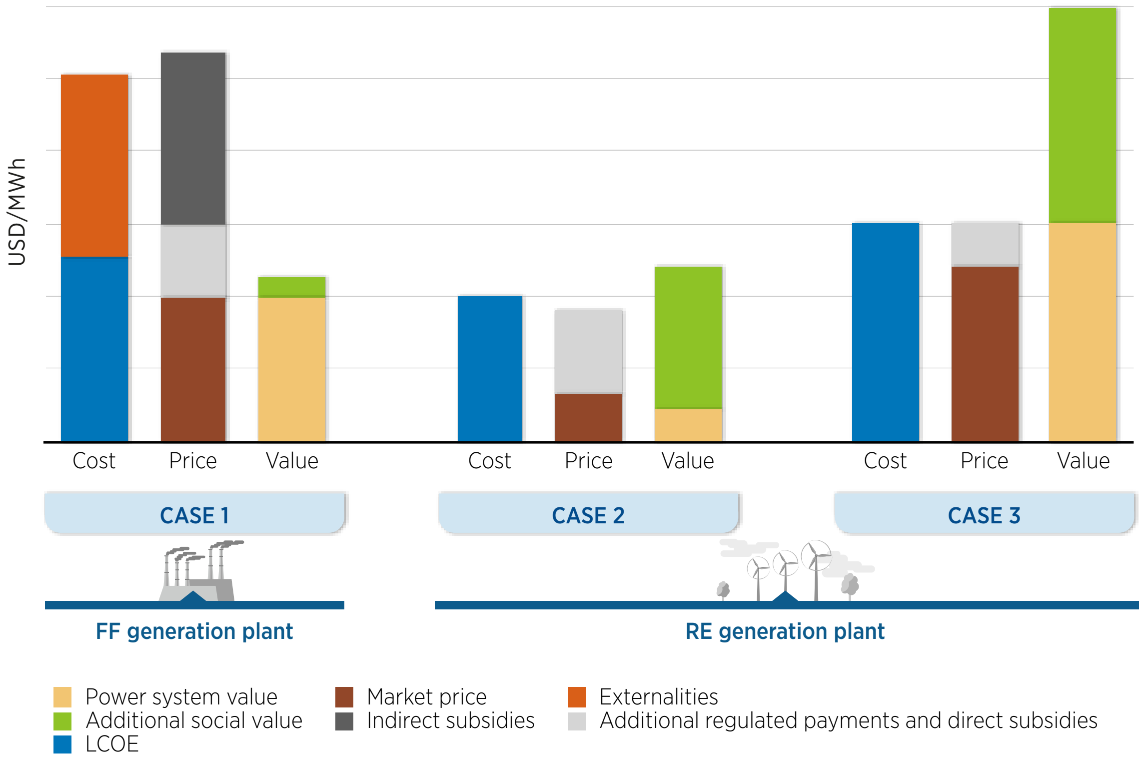
Similar barriers can develop following the implementation of carbon or fossil fuel taxes, often with similar impacts for end users as a reduction in fossil fuel subsidies: an increase in prices. The gilets jaunes (yellow jackets) movement is a case in point, originating in France in 2018 triggered by an increase in fossil fuel taxes (carbon taxes), ultimately preventing those taxes from being implemented (Martin and Islar, 2021; Mehleb, Kallis and Zografos, 2021).

Ultimately the social dimension of climate policy, including adequate communication and enhanced governance, holds the key for successful results (Bergquist, Mildenberger and Stokes, 2020; Lamb *et al.*, 2020).

* Fossil fuel subsides can come in the form of both direct (support to consumption or production) and indirect (externalisation of social and environmental impacts) subsidies.

Case 2.[36] Moreover, since the power system structure in Case 2 is not fit for renewable power, it needs higher additional regulated payments because of the depressed wholesale electricity prices as renewables penetration increases. On the other hand, the organisational structure considered in Case 3 is appropriate for the characteristics of a renewable-based power system (see chapter 6) and hence prices the generated electricity in a way that is well aligned with both its costs and system value.

FIGURE 26. Cost, price and value of electricity (illustrative annual averages)



Note: FF = fossil fuel; LCOE = levelised cost of electricity; RE = renewable energy.

For a more nuanced discussion of these examples, see IRENA (2020c).

As illustrated in this section, the cost, price and value misalignments can have profound implications for the power sector and for the outer systemic layers (economy and society). But there are other misalignments beyond the power system that can significantly hinder the energy transition, as discussed in the next section.

4.2. MISALIGNMENTS BEYOND THE POWER SYSTEM

A successful transition requires a systemic approach, paying attention to the interactions and feedbacks between the different systemic layers (chapter 1). Misalignments in systemic layers beyond the power system (energy system, economy, society, Earth) do have important effects on the power system, and hence need to be addressed by a holistic transition planning and policy framework. This report focuses mainly on the power system, addressing how to overcome the misalignments within this system. However, misalignments beyond the power system that have important implications for it and for the transition itself are briefly discussed in this section, providing the necessary background

[36] Many combinations of technologies and how they are implemented and operated may lead to these differences. For instance, Case 3 could involve dispatchable renewable energy technologies (such as CSP or solar PV with battery storage) built and operated with higher emphasis on maximising its social value. Alternatively, Case 3 could represent an off-grid application of renewables with high social value and deployed within an organisational structure that properly aligns price, costs and system value.

to foster a holistic approach that allows power system organisational structures to contribute their share in addressing these misalignments.

Most misalignments beyond the power system are not the unique preserve of the energy transition. They existed before this transition and have co-existed with fossil fuel power and energy systems for a long time. But the current critical environmental and social framework makes addressing these misalignments a fundamental cornerstone for a successful energy transition (chapter 1).

Misalignments related to labour, unlimited growth and inequalities, as well as the implications for the energy transition, are discussed below.[37] These misalignments will not be sorted out by merely transitioning to a renewable-based energy system (unlike those discussed in Box 18). Hence a holistic policy framework spanning all systemic layers will be needed to address these misalignments and prevent the barriers to transition that they could produce.

Labour dynamics during the transition

The energy transition will bring about a restructuring of the labour market, potentially increasing the availability of employment in some sectors while reducing it in others, which can lead to labour misalignments. Because the power sector is called to play a central role in the energy transition, many of the potential job misalignments can originate within it and then ripple through the rest of the economy. Given the links and feedbacks between the different systemic layers (chapter 1), employment impacts propagate beyond the energy sector, affecting the outer systemic layers (economy, society). A holistic policy approach to the energy transition can take advantage of these systemic interactions,[38] fostering synergies across the different systemic layers and sourcing solutions to the labour challenges generated within the energy sector while simultaneously addressing challenges in other systemic layers.[39]

With the appropriate ambition and policies in place, the energy transition can bring about an increase in transition-related jobs (renewables, efficiency, flexibility) that exceeds the loss of fossil fuel-related jobs that it entails. However, the transition's labour impact presents a strong regional dependence, driven by how regional[40] and global[41] structural socio-economic elements play out in each situation.

But even if the new transition-related jobs outnumber the lost fossil fuel jobs in aggregated terms, several labour misalignments can take place. Sectoral misalignments are associated with some economic sectors losing jobs in absolute terms during the transition. Temporal misalignments happen when new jobs appear at a different point in time than lost jobs. Spatial misalignments refer to new job opportunities being produced in different geographical locations than those where jobs are being lost. Educational misalignments happen when the training and skills required by the new jobs differ from those of the lost jobs.

Addressing labour misalignments requires a holistic just transition policy framework (IRENA, Ferroukhi, García Casals and Parajuli, 2020). To inform this policy framework, IRENA has been exploring the likely transition labour dynamics through the evaluation of the socio-economic footprint of transition roadmaps (IRENA, 2021c, 2019d, 2018, 2016b, Ferroukhi, García Casals and Parajuli, 2020). Figure 27 presents

[37] Besides these three, there are other misalignments beyond the power system that through systemic interactions can jeopardise the transition. This report does not aim to present an exhaustive coverage of misalignments beyond the power sector, but rather to point out that these misalignments exist and hence a holistic approach is required. These three misalignments have been chosen because of their direct implications for the power sector and its associated transition dynamics.

[38] Such a holistic approach is also required to address other employment challenges that will arise because of other megatrends (such as automation, artificial intelligence or demographic dynamics) that will be deploying in parallel with the energy transition.

[39] This could be, for instance, done by increasing the public offer of caring economy employment to simultaneously address social challenges and the labour misalignments introduced by the energy transition.

[40] Such as policy ambition and a holistic policy approach, fossil fuel dependency, and the strength and depth of local supply chains.

[41] Such as trade agreements, commercial links and other international economic relations.

Box 18. Pre-transition misalignments that can be mitigated by transitioning towards renewables: The case of climate change and air pollution

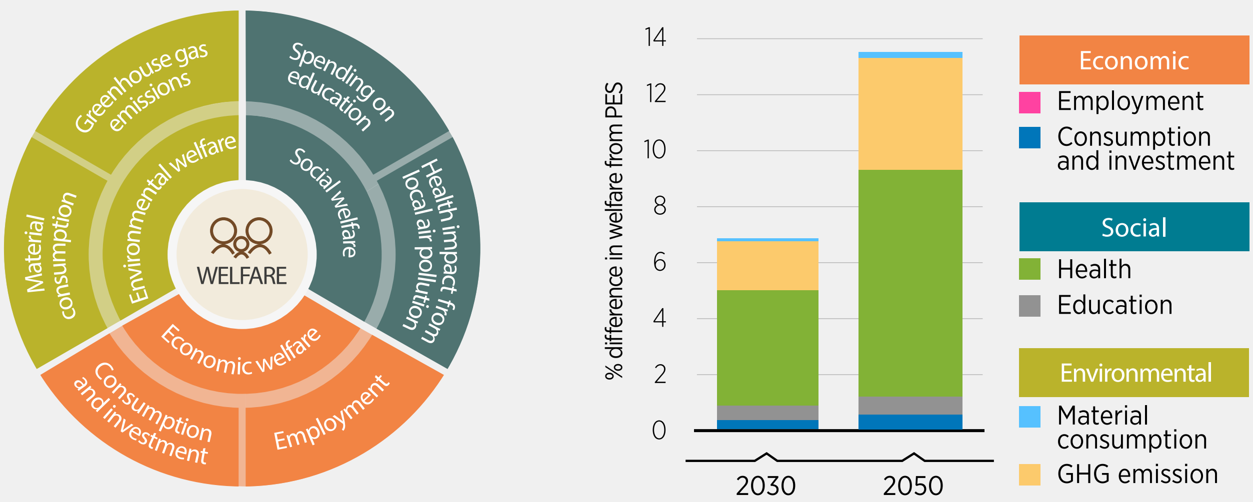
The consumption of ever-increasing amounts of energy during the fossil fuel era has left the legacies of climate change and air pollution, the latter especially impacting urban areas around the world. Power generation has contributed greatly to these legacies. Climate change and air pollution have severe negative impacts on the health and welfare of populations, which constitutes an important misalignment of the current energy system. Given the increasing trends of population and per capita energy services demanded by this population, in the absence of a significant energy transition away from fossil fuels towards renewables, these impacts would increase significantly.

Because the power system is a cornerstone of the energy transition, potentially facilitating the faster deployment of renewables in end-use sectors (energy system integration through direct and indirect electrification), it can play a very important role in reducing both air pollution in urban areas and climate change.

To analyse the socio-economic footprint of energy transition roadmaps, IRENA uses a welfare index that up to 2021 had* three dimensions (social, environmental and economic) and six indicators (spending on education, health impacts from local air pollution, material consumption, greenhouse gas emissions, consumption and investment, and employment). Figure 27 presents the global welfare results of IRENA's energy transition roadmap (REmap), expressed as the welfare index improvement between the transition scenario (TES) and a reference scenario consistent with the currently planned policies (PES), by 2030 and 2050. The improvement in the welfare index increases as the transition progresses and is strongly dominated by the improvement in the health impacts from local air pollution, followed by the mitigation of greenhouse gas emissions.

Hence the transition to a renewable-based energy system directly addresses the pollution and climate change misalignments, bringing about a very important improvement in welfare.

FIGURE 27. IRENA's welfare index: Structure with its three dimensions and six indicators and results of its global improvement by 2030 and 2050 during the REmap transition roadmap



Note: C&I = Consumption and Investment; GHG = greenhouse gases.
* In 2021 the IRENA Transition Welfare Index was expanded to 5 dimensions (adding distribution and energy access) and 10 indicators (IRENA, 2021c).
Source: IRENA, 2020b.

results from IRENA's 2019 transition roadmap[42] for two regions: Southern Europe[43] and the Gulf Cooperation Council (GCC).[44] Job results are provided for renewable energy, the energy sector and economy-wide, so that insights on potential sectoral misalignments can be derived. For each region, Figure 27 presents two sets of results: the time evolution of jobs under the transition (TES) scenario (2017-2050) and the difference in jobs between both scenarios (TES and PES) in 2050.

The time evolution of jobs for both regions under the TES scenario is similar in terms of the increase of jobs between 2017 and 2050, despite significant differences in the absolute number of jobs for each region. Jobs increase in renewable energy, in the energy sector, and in the whole economy, with the energy sector experiencing the highest increases. However, these job increases are to a large extent driven by the baseline expansion of the economy assumed for these scenarios. Indeed, under the TES the global economy grows between 2019 and 2050 at a compound annual growth rate of 3.1%, with the Southern European and GCC economies expanding at compound annual growth rates of 1.7% and 3.3% respectively.[45]

Hence the effect of this transition roadmap and the potential misalignments it may induce have to be analysed by comparing the employment evolution across the two scenarios: the PES (no transition beyond current policies) and the TES (transition). The right panel in Figure 27 provides this information: by 2050 the transition's impact on jobs in these two regions is very different, as a consequence of how regional and global socio-economic structural elements play out in each of the regions.

In Southern Europe, several factors contribute to a positive employment impact in all the considered dimensions (renewables, energy sector and economy-wide). These factors include: a limited fossil fuel dependency of its domestic supply chains; the positive trade impact associated with reducing fossil fuel imports; the level of energy transition ambition; the existence of strong and diversified domestic supply chains; and transition fiscal policies that trigger positive economy-wide interactions through induced effects.

Employment in the energy sector in Southern Europe increases slightly more than employment in renewable energy, indicating that the decrease in fossil fuel-related jobs is more than compensated by an increase in other transition-related jobs (efficiency and flexibility). Economy-wide jobs experience an increase significantly higher than energy sector jobs, indicating that positive economic feedbacks lead to employment increases in other economic sectors beyond the energy sector. Hence this region does not experience sectoral labour misalignments during the transition, but rather positive systemic feedbacks.

In the GCC region the situation is very different, with employment sectoral misalignments happening both within the energy sector and in the rest of the economy. This is driven by several factors including: a strong fossil fuel dependency of its economy, with negative trade impacts resulting from the transition; strong fossil fuel dependency and lack of diversification of domestic supply chains.

Figure 28 shows a lower increase in energy sector jobs in the GCC region than the increase in renewable energy jobs, meaning that the loss of fossil fuel jobs is significantly higher than the increase in other transition-related jobs (efficiency and flexibility) and almost neutralises the overall increase in transition-related jobs (renewables, efficiency and flexibility). Economy-wide jobs are lower for the transition scenario, and since energy sector jobs are slightly higher in the transition, other sectors of the economy experience a reduction in employment as a consequence of the systemic feedbacks between the energy sector and the economy.

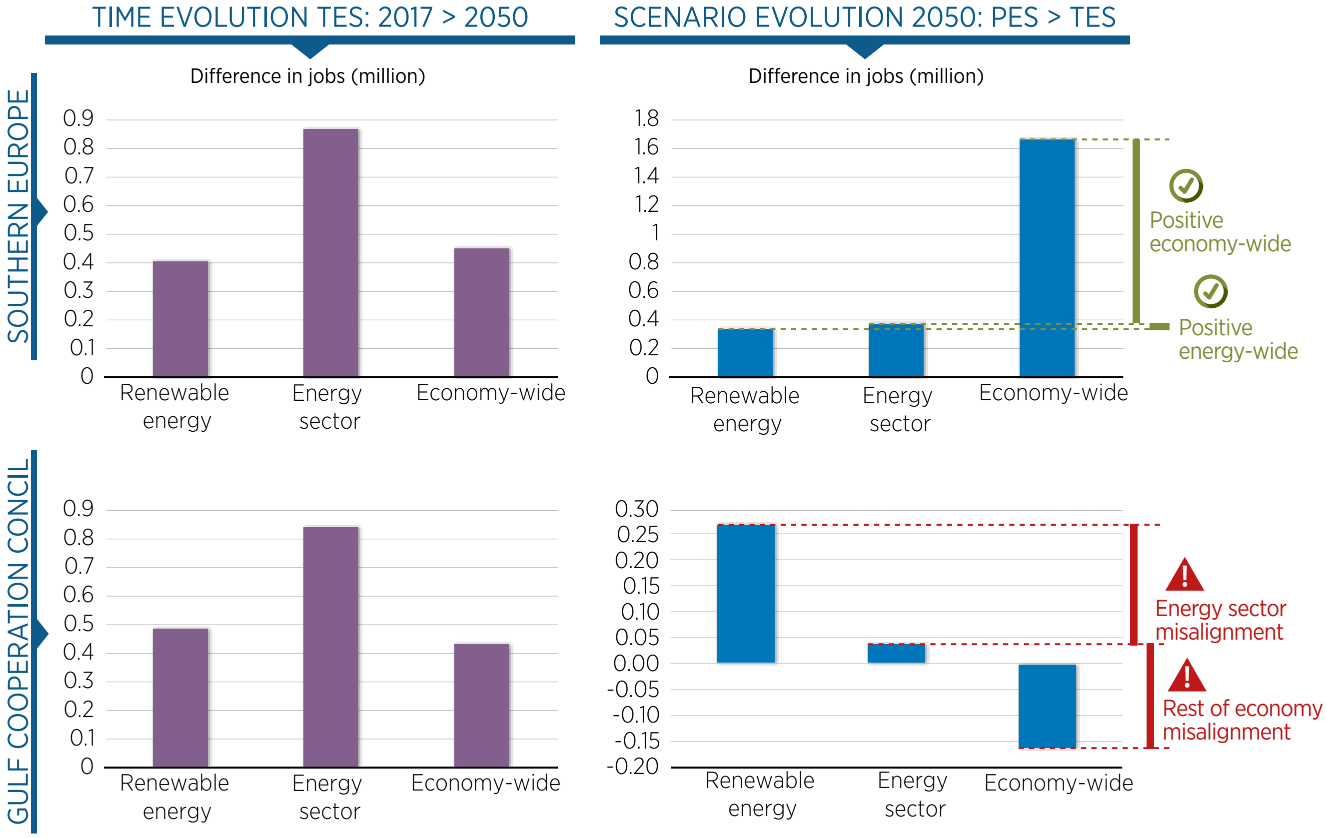
[42] This transition roadmap includes two scenarios: the Planned Energy Scenario (PES), which captures the current policies; and the Transforming Energy Scenario (TES), which considers an increased transition ambition from that captured by current policies.

[43] The countries included in Southern Europe are: Croatia, Cyprus, Greece, Italy, Norh Macedonia, Portugal, Slovenia and Spain.

[44] The countries included in the GCC region are: Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates.

[45] These compound annual growth rates mean that, by 2050, the Southern European economy will be around 70% bigger than in 2019, and the GCC economy will be around 170% bigger.

FIGURE 28. Difference in jobs in renewable energy, energy sector and economy wide from 2017 to 2050 for the transition scenario (TES) (left panel) and between the planned (PES) and transition (TES) scenarios in 2050 (right panel). Results for Southern Europe and the Gulf Cooperation Council.



IRENA's analysis also indicates that the labour implications of renewable energy deployment are favourable for women. Women account for a higher share of the renewables workforce (32%) than is the case in the oil and gas sector (22%) (IRENA, 2019e). However, educational misalignments, especially in developing countries, if not properly addressed, can represent a barrier to fulfil the energy transition's potential to involve women in the energy sector.

The results presented above showcase how the regional and global socio-economic context under which the transition develops can produce sectoral job misalignments. Misalignments are likely to happen in the temporal, spatial and educational dimensions, requiring a comprehensive and holistic just policy approach to prevent negative impacts and barriers to transition. Because the power sector lies at the core of the energy transition, many of these job misalignments can originate within it, propagating to the rest of the energy sector and the economy, while others can trickle down from outer systemic layers and affect the power sector. Hence, due attention needs to be given to the socio-economic dimension of power system organisational structures, so that they can help to address cross-cutting job misalignments.

The imperative to increase aggregated economic activity

The power system will be subject to strong opposing trends during the transition, with the potential to significantly change its size and structure. On the one hand, energy efficiency deployment will introduce a trend towards reducing electricity demand. On the other hand, energy system integration through direct and indirect electrification introduces a strong trend towards increasing electricity demand. Underlying these, there is an additional trend from the economy systemic layer that will likely push energy (and hence electricity) demand upwards to underpin the imperative for increased global aggregated economic activity, despite efforts to decouple energy use from GDP growth (see Box 19).

Transitioning today's energy and power systems towards renewables within the time window available for climate consistency is already a huge challenge. Adding the global economy's growth imperative on top of it makes the task still more difficult, because renewable energy deployment has to deal simultaneously with the substitution of the existing fossil fuel infrastructure and coping with the additional energy demand linked to increasing global aggregated economic activity. Hence the chances of successfully transitioning within the available climate time window would increase greatly if the economic growth imperative were relaxed.[46]

The imperative to continuously increase aggregated economic activity has dominated economic policy and mainstream economics since the classical economists of the 19th century. Today, it is so deeply embedded in our socio-economic structure that any slowdown in economic growth triggers deep crisis episodes (recessions, depressions). The way that socio-economic systems are currently structured is such that if economic growth stops, jobs are lost, businesses close and people lose access to fundamental basic services (food, housing, health, transport, etc.). However, the current socio-economic structure is a social construct: there is nothing that prevents societies from introducing structural changes to adapt organisational structures to the prevailing systemic boundary conditions, while simultaneously improving them.

In the past, while the social system was relatively small compared to the size of the outer systemic layer (Earth system), increasing global economic activity did not produce evident negative macro impacts. However, since the mid-20th century, it has been increasingly evident that these impacts exist and are unsustainable because of transgressing several planetary boundaries. Climate change is one of the main impacts, but others include biodiversity loss and air pollution (Rockström *et al.*, 2009; Steffen *et al.*, 2015).

Although economic growth has brought important progress in social dimensions, this does not rule out the possibility of this progress or even improved progress to be achieved with other socio-economic structures. Indeed, there is mounting evidence that unequal economic growth could be an inefficient way of pursuing shared global prosperity, and that increasing aggregated economic activity is subject to a saturation process in the sense that beyond a certain threshold it does not produce additional social improvements (Jackson, 2017).

Moving from a stand-alone consideration of the economy to a systemic approach, it becomes evident that the economic activity has both lower and upper activity boundaries. The lower activity boundary is to prevent shortfalls in social needs; the upper activity boundary is to avoid overshooting the Earth system capacity. It is within these two boundaries where a safe and just space for humanity to thrive exists (Raworth, 2017). Hence in recent years increasing efforts have been made to address these structural changes, which would allow humanity to transition from past socio-economic structures towards mature ones signalling the end of the growth phase (O'Neill *et al.*, 2018; Trebeck and Williams, 2019).

Transitioning our societies towards sustainability while maintaining the imperative of continuously increasing aggregated economic activity would require a very strong decoupling of GDP from emissions and material consumption. Recent analyses of historic evidence of decoupling and the prospects provided by several scenarios are not encouraging in terms of the capability to achieve and sustainably maintain the required rates of decoupling (see Box 19).

[46] This applies differently depending on the status of each country. While growth is still necessary in some countries to enable the population to advance in the prosperity ladder, in other countries further growth can trigger barriers for a shared prosperity and for the energy transition itself.

Box 19. Decoupling energy and CO_2 emissions from GDP growth

For economic growth to be sustainable, it needs to be decoupled (in absolute terms) from both resource use and greenhouse gas emissions (UNEP, 2011). United Nations Sustainable Development Goal 8 (Target 8.4) directly points to the necessity to decouple economic growth from environmental degradation (UN DESA, 2015). However, there is growing consensus that not any kind of decoupling will do; specifically, decoupling for sustainable development needs to be global, absolute, fast enough and long enough (Vadén *et al.*, 2020).

A key distinction is between relative and absolute decoupling. Relative (weak) decoupling occurs when resource use or some environmental pressure grows at a slower rate than the economic activity that is causing it, whereas absolute (strong) decoupling occurs when resource use or environmental pressure declines while the economic activity continues to grow (IRP, 2017).

Reductions of energy intensity (EI) and emissions intensity of energy (EmI_E) over time indicate a decoupling of energy and economic activity (EI) and greenhouse gas emissions and energy use (EmI_E). For this decoupling to be absolute, the reduction rate of EI and EmI_E need to be higher than the growth rate of GDP and energy use respectively; otherwise the decoupling is only relative.

Decoupling of resource use (including energy) is much harder to achieve than decoupling from greenhouse gas emissions. Energy decoupling depends on the deployment of energy efficiency, whereas emissions decoupling benefits from both energy efficiency and the deployment of renewables.

Historically there has been a positive correlation between economic growth (measured as GDP) and resource use and greenhouse gas emissions, although with clear relative decoupling even in terms of energy use (Guo, Li and Wei, 2021).

Empirical evidence of absolute decoupling is scarce (Wiedenhofer *et al.*, 2020). Regarding resource use at a global level, there is no empirical evidence of absolute decoupling (Hickel and Kallis, 2020).

Several countries have already achieved absolute decoupling of CO_2 emissions (Hausfather, 2021). This decoupling is clearly feasible, since it is a direct outcome of the transition towards a zero-carbon energy system. However, there are serious concerns about whether this can be done fast enough globally to address climate breakdown (Hickel and Kallis, 2020; Li, 2020; Parrique *et al.*, 2019; Schröder and Storm, 2020; Tilsted *et al.*, 2021).

Absolute energy decoupling has also been achieved in a few high-income countries (Ritchie, 2021). However, this seems difficult to attain globally, because of the structural differences between developed/high-income countries and developing/low-income countries (Guo, Li and Wei, 2021; Schröder and Storm, 2020; Steinberger *et al.*, 2013; Wu, Zhu and Zhu, 2018). The existence of an income tipping point at which energy use is absolutely decoupled from GDP growth (energy-environmental Kuznets curve) has been found in industrialised and high-income countries, but does not seem to be applicable to low- and middle-income countries.

Moreover, the permanence of the decoupling for essential, non-substitutable resources (such as energy) could be impossible because the efficiency gains are ultimately governed by physical limits (Ward *et al.*, 2016). Hence as the physical limits of resource efficiency are eventually reached, continued GDP growth would drive resource use back up (Hickel and Kallis, 2020).

Energy transition pathways and the transition's link with the economic system are mainly characterised by the evolution of the energy intensity of the economy (EI, or energy used per unit of GDP), which relates to the deployment of energy efficiency, and by the CO_2 emissions intensity of energy ($EmI_{E,}$ or emissions per unit of energy used), which describes the decarbonisation of the energy sector.

The climate consistency of the energy transition is linked to its CO_2 mitigation rate, which in turn is associated with the remaining carbon budget.[47]

For any energy transition roadmap (characterised[48] by the evolution of EI and EmI_E), there is a direct link between the CO_2 mitigation rate it provides and the growth rate of the economy. Figure 29 presents[49] this relationship for historic data and four[50] transition pathways[51] at the global level.[52] Points indicating the different scenarios from IRENA and the IEA (PES/STEPS, TES/SDS and 1.5S/NZE) have also been included. In addition, the figure presents the emissions mitigation rates corresponding to complying with the available 2021 carbon budgets for 2°C of warming at 67% likelihood and for 1.5°C at 50% likelihood as per the IPCC's 1.5°C Special Report (1.5SR) and Sixth Assessment Report (AR6) (IPCC, 2021, 2018).

Several important conclusions can be extracted from the analysis presented in Figure 29:

- For any technological characterisation of a transition roadmap (given by its efficiency and decarbonisation deployment), the higher the annual CO_2 mitigation rate, the lower the growth in GDP. Hence as mitigation requirements increase (to adjust to ever reducing carbon budgets) the margin for maintaining positive economic growth declines.
- For an evolution of EI and EmI_E improvements such as those associated with current policies like IRENA's PES (IRENA, 2020b) and the IEA's STEPS (IEA, 2021b), reducing global aggregated economic activity is a must for avoiding global warming beyond 2°C.
- For the technological characterisation of efficiency (EI) and decarbonisation (EmI_E) deployment implemented in mainstream transition scenarios such as IRENA's TES (IRENA, 2020b) and the IEA's SDS (IEA, 2021b), economic growth can be maintained for climate goals consistent with a 2°C global

[47] If we consider the carbon budgets provided in IPCC (2018), the emissions compound annual degrowth rate associated with limiting global warming to 2°C with 67% likelihood and 1.5°C with 50% likelihood are 4.5% and 15.3% respectively. When considering the carbon budgets provided in IPCC (2021) the compound annual degrowth rate of these emissions is 3.5% and 8.5% respectively.

[48] Note that specifying the evolution of EI and EmI_E to characterise the energy transition roadmap already includes the effect of all aspects that can be considered during the energy transition, such as the deployment of energy efficiency and renewables, as well as structural aspects like the incorporation of circular economy and behavioural changes.

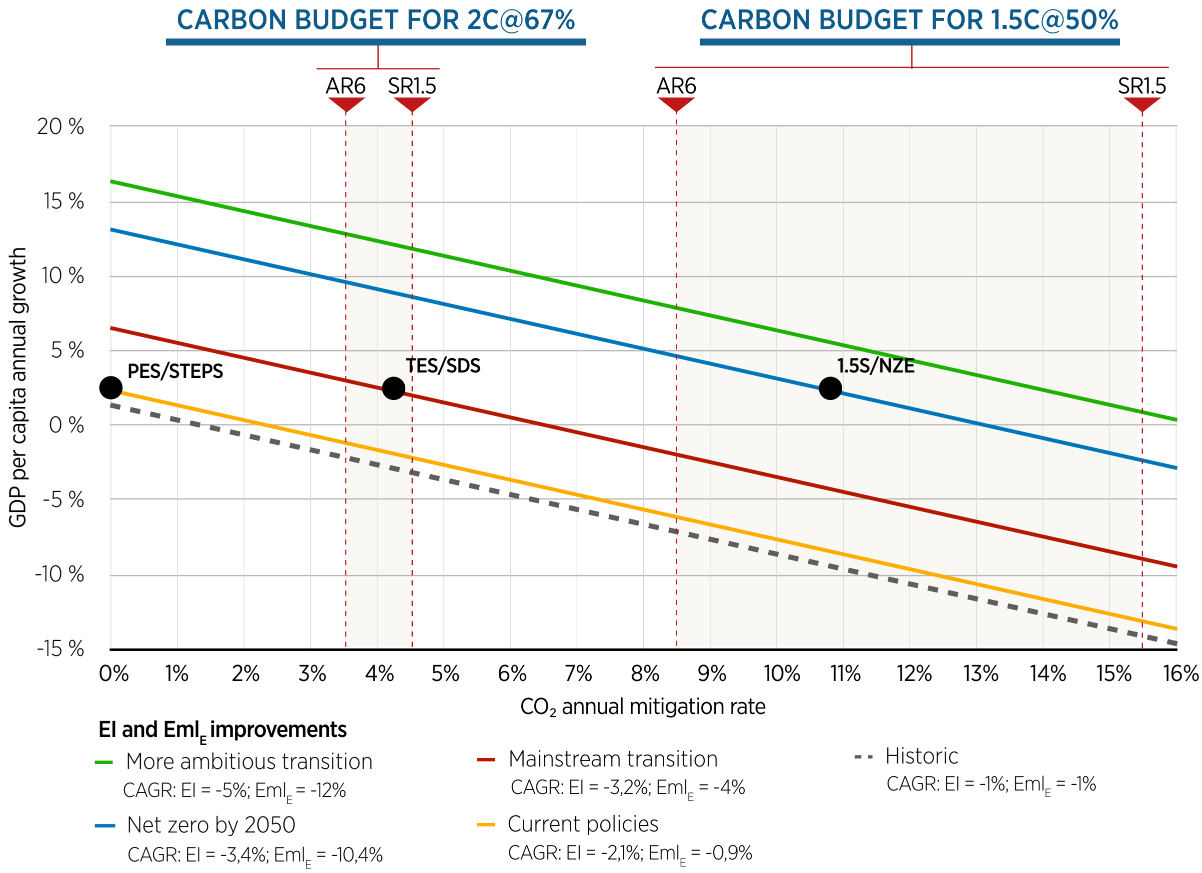
[49] The presented analysis is based on the Kaya identity, considering a 0.65% compound annual growth rate for global population, as in IRENA (2020b). Under these conditions, the Kaya identity relates economic growth with the three variables described above (CO_2 emissions, energy intensity and CO_2 emissions intensity of energy). Note that this is an identity, and not an equation derived from a model, and hence the Kaya identity must always be fulfilled.

[50] The historic pathway is technologically characterised by improvement rates of EI and EmI_E aligned with historic values (-1% per year for both EI and EmI_E). The first transition pathway (current policies) is technologically characterised by improvement rates of EI and EmI_E as found in mainstream reference scenarios, such as IRENA's PES (IRENA, 2020b) and the IEA's STEPS (IEA, 2021b). The second transition pathway (mainstream transition) is technologically characterised by improvement rates of EI and EmI_E as found in current main energy transition proposals such as IRENA's TES (IRENA, 2020b)and the IEA's SDS (IEA, 2021b). The third transition pathway (net zero by 2050) is technologically characterised by improvement rates of EI and EmI_E, as found in transition scenarios aiming at net zero CO_2 emissions by 2050, such as IRENA's 1.5S (IRENA, 2021c) and the IEA's NZE (IEA, 2021b). Finally, the fourth transition pathway (more ambitious transition) is technologically characterised by additional improvements of efficiency deployment (EI -5% per year) and decarbonisation rates (EmI_E -12% per year).

[51] Each technologically defined by the improvement rates of EI and EmI_E, both expressed as compound annual growth rates. It should be noted that carbon budgets and the associated required mitigation rates refer to total CO_2 emissions, *i.e.* energy, process and LULUCF (land use, land use change and forestry). Energy scenarios such as those from IRENA and IEA do not include an analysis of LULUCF mitigation. Therefore, when presenting points representative of these scenarios in Figure-29 the assumption is that the mitigation effort in LULUCF emissions is equivalent to that in energy and process emissions, *i.e.* LULUCF emissions are proportional to energy and process emissions. If mitigation effort in LULUCF would be lower than that applied in energy and process emissions, then the points representative of IRENA and IEA scenarios would move to the left in Figure-29 (lower overall mitigation rates).

[52] Global economic growth rates can include very different country-level economic growth rates that recognise the different needs of countries to provide prosperity.

FIGURE 29. GDP growth rate as a function of the CO_2 emission mitigation rate for different transition pathways characterised by the compound annual growth rate of energy intensity (EI) and the emissions intensity of energy (EmIE)



warming. But when aiming for a 1.5°C climate goal, these levels of efficiency and decarbonisation deployment would require significant reductions in global aggregated economic activity.

- When implementing efficiency (EI) and decarbonisation (EmI_E) deployment rates like those featuring in scenarios aiming at net zero emissions by 2050, such as IRENA's 1.5S (IRENA, 2021c) and the IEA's NZE (IEA, 2021b), the 1.5°C climate goal could be reached while maintaining positive growth rates of aggregated global economic activity in more than half the range of the required mitigation rate as per the carbon budgets provided in AR6 (IPCC, 2021) and SR1.5 (IPCC, 2018).
- By increasing the rates of efficiency and decarbonisation deployment, the margin to maintain growth for different climate goals increases. However, even for a fairly ambitious transition (5% per year reduction of EI and 12% per year reduction of emission intensity of energy use), the 1.5°C at 50% likelihood climate goal – as per the lower estimates of the remaining carbon budget, such as those derived from the SR1.5 (IPCC, 2018) – would require an almost steady-state economy.

Degrowth is not an imperative for the energy transition to comply with climate goals, as proposed by many references that tend to underestimate the potential for efficiency and decarbonisation deployment (Hickel and Kallis, 2020; Li, 2020; Schröder and Storm, 2020). But, critically, limiting growth or even being able to organise our socio-economic system to thrive under reducing aggregated global economic activity increases the chances of complying with ambitious climate goals.[53]

[53] Hence the challenge is achieving an evolution of the aggregated economic activity that is economically, environmentally and socially sustainable. Among other things, this would mean a different distribution of the evolution of aggregated economic activity, with higher rates in poorer countries and lower rates in richer ones, but also with higher growth for poorer versus richer people.

Our current socio-economic structure collapses under a degrowth context. To comply with ambitious climate goals that prevent catastrophic impact on our socio-economic system, there is likely a need to move into the area of Figure 29 with lower aggregated global economic activity growth rates than those experienced in the past (to a higher or lower extent depending on how fast efficiency and decarbonisation are deployed). Hence addressing structural aspects that allow our socio-economic systems to progress and thrive under lower aggregated global economic activity growth rates is becoming a priority.

A steady-state economy could be an appropriate goal for human activity on a planet with finite resources and impact-bearing capacity. The concept of a steady-state economy was already in the mind of leading classical economists such as Adam Smith and John Stuart Mill in the 18th and 19th centuries, as well as in the thoughts of some of the most influential 20th century economists, such as John Maynard Keynes. To reach a steady state of the global economy, some countries will have to grow further in order to satisfy basic social needs, while other countries where economic activity has surpassed the carrying capacity of the ecosystems that contain it will need to reduce their aggregated economic activity.

Hence the transition challenge to overcome this misalignment is two-fold:

- Reduce as fast as possible and without further delay both the energy intensity (EI) of the economy and the emission intensity of energy (EmI_E). The margin to accelerate them, and especially the reduction in EmI_E, is still very high.
- Introduce structural changes that reduce or eliminate the current dependency of our economies on continuous and unlimited increasing economic activity.[54]

Only advances on both these fronts allow for increasing the ambition of the energy transition (*i.e.* increasing the emission mitigation rate), and therefore limiting the impacts of climate change on socio-economic systems. Currently the main focus of the energy transition has been on reducing EI and EmI_E, but the contribution of advances in improving the structure of socio-economic systems would be very much welcome to successfully address sustainability challenges.

Power system organisational structures and the economic growth imperative misalignment are related at multiple levels: organisational structures are an important determinant of the resulting energy transition roadmap (evolution of EI and EmI_E); organisational structures are directly impacted by the evolution of economic growth and the climate impacts resulting from it; and organisational structures have the capability of helping to facilitate the kind of economic activity that enables higher CO_2 mitigation rates. Hence a holistic vision is needed in the redesign of power system organisational structures, so that synergies may be maximised and barriers are avoided.

Inequality undermines collaboration

Inequality in the distribution of income, wealth and options/opportunities, as well as inequality in access to basic services,[55] deeply undermines socio-economic systems through the degradation of social welfare,[56] democracy[57] and ecosystems,[58] as well as contributing to economic instability and even undermining economic growth (Hickel, 2017a; Raworth, 2017; UN DESA, 2020).

[54] Currently this would require differentiating with equity criteria across countries between those that still need to increase their aggregated economic activity and those that do not anymore. The latter countries ultimately would make the knowledge about how to structure economies to flourish within planetary boundaries available for all countries to evolve at their own pace towards this steady-state condition.

[55] Such as health, education, energy, water and food.

[56] With many impacts, including teenage pregnancy, mental illness, drugs, obesity, prisoners, school dropouts, community breakdown, lower life expectancy, lower status for women and lower trust (which inhibits collaborative frameworks).

[57] Power concentration and exclusion.

[58] By fuelling status competition fed by ever increasing consumption and eroding the social capital needed to conserve the commons.

Addressing the climate emergency with chances of success in limiting global warming to prevent disastrous climate impacts on socio-economic systems requires an unprecedented global collaborative effort. Triggering and maintaining such a collaborative effort needs a very solid social contract, based on justice and fairness, that leaves no one behind.[59]

Hence inequality is a major misalignment of the current socio-economic system that can seriously hinder the success of the transition. In its updated welfare Index, IRENA has incorporated a distributional dimension (IRENA, 2021c) to gain insights about the transition's implications for inequality and the policies needed to address it.

Having a look to the historic evolution of inequality can be difficult because of the different metrics in use. Indicators can target inequality within countries, among countries or for global citizens,[60] and they can be formulated in relative or absolute terms[61] (Hickel, 2017b; World Bank, 2016).

Relative income inequality within countries is very high and since 1990 has increased in countries that are home to more than two-thirds of the world's population.[62] Relative income inequality among countries[63] is still higher than inequality within most countries, but it recently declined after a prolonged period of continuous increases. However, absolute[64] income inequality between countries continues to grow, with the absolute gap between the mean per capita incomes of high- and low-income countries increasing from around USD 27600 in 1990 to more than USD 42800 in 2018 (UN DESA, 2020).

Additionally, income inequalities have a clear gender dimension as women all over the world are underrepresented in high-profile jobs, which tend to be better paid, and are overrepresented in low-paying and non-remunerated jobs (Figure 30). Economic inequalities related to gender are evident not only in wages earned, but also in ownership of productive assets. Including in many developed countries, women are less likely to get a loan for productive purposes (Demirgüç-Kunt *et al.*, 2018), reducing their ability to start, operate or expand an economic activity.

[59] Beyond solidarity, in the current climate crisis this has become a must. Transition dynamics in an unequal and unfair world would lead to the majority of the population getting access to very cheap (because of the reduced demand from the Global North) fossil fuels and fossil fuel technologies. This could easily reverse any decarbonisation advancements in the Global North by the pursuit of a replication of the Global North's fossil fuel-based economic growth of the past decades.

[60] The global income distribution among the world's population.

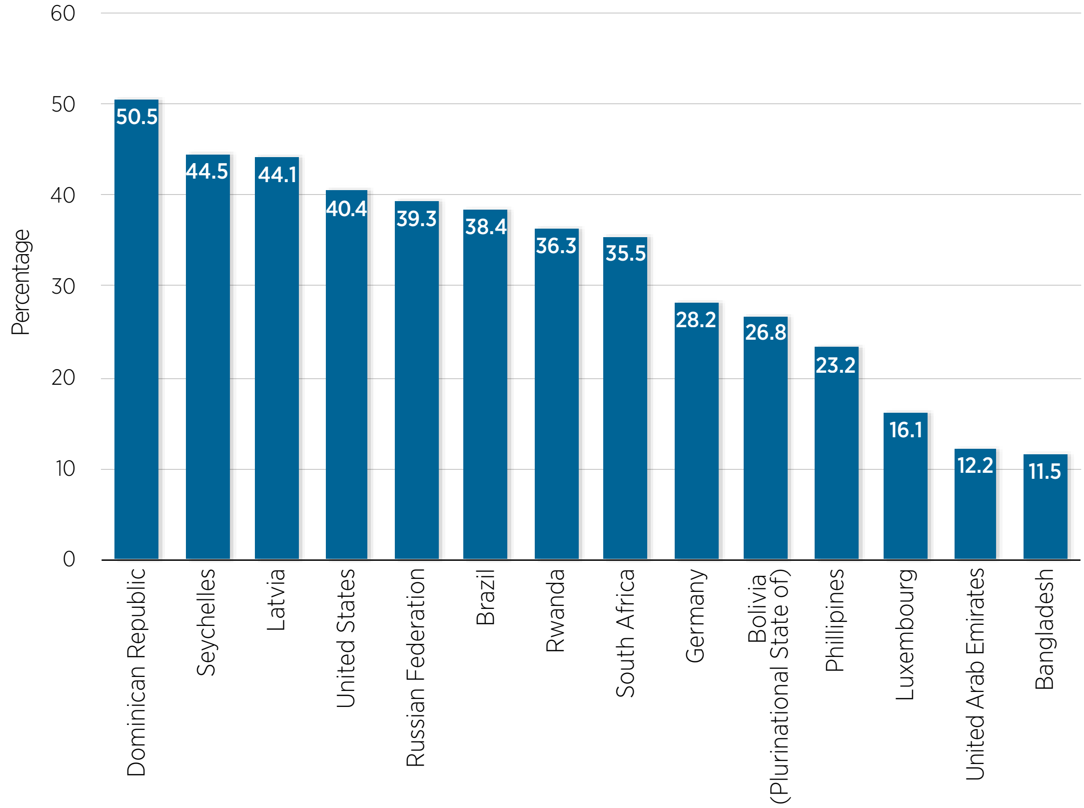
[61] Relative inequality measures distributional differences in relative terms, whereas absolute inequality evaluates the distributional differences in absolute terms.

[62] Including most developed countries and some middle-income countries.

[63] Calculated using population-weighted national incomes per capita.

[64] People perceive and experience absolute inequalities in their daily lives, in terms of living conditions and well-being (UN DESA, 2020).

FIGURE 30. **Proportion of women in senior and middle management positions in selected countries, 2017**



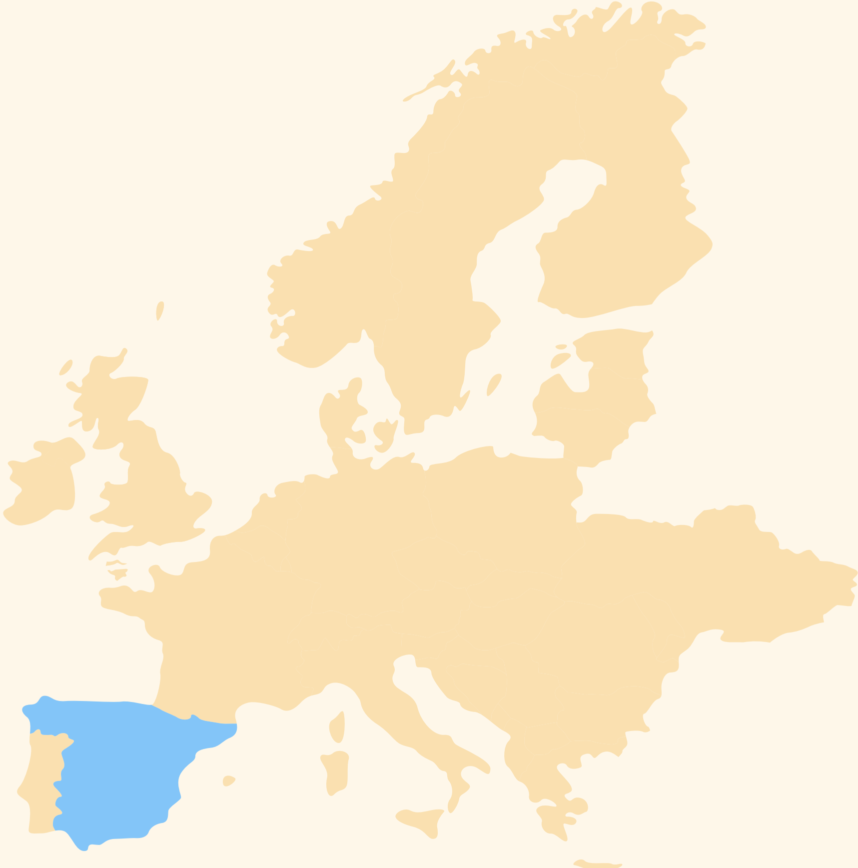
Source: ILO (2022).

The currently huge global inequality and its evolution under a socio-economic business-as usual undermines any options to build the needed social contract for successfully addressing the climate and biodiversity crises. This becomes clear when considering the existing carbon inequality: the richest 10% of the world's population has been responsible for 52% of the cumulative carbon emissions from 1990 to 2015;[65] the poorest 50% has been responsible for just 7% of these cumulative emissions, while at the same time bearing the bulk of climate impacts (Oxfam, 2020).

The most disadvantaged groups are also the most vulnerable to the impacts of climate crisis and the least resilient due to socio-economic structures that exclude them from access to resources, decision making or agency (Dunne, 2020; Watts *et al.*, 2018). Moreover, as discussed above, under a transition context driven by the need to limit global warming, the room for increasing global aggregated economic activity shrinks with requirements for increased CO_2 emission mitigation rates. Under this context, improving the distribution of output and wealth (reducing inequality) within and between countries becomes one of the pillars needed for a stable socio-economic system. To advance a meaningful transition that avoids disproportionate burdens for any group of people, it is key to meaningfully involve all in the design, implementation and enforcement of the energy transition and its organisational structures.

The power system sits at the core of the transition process. Through its links and feedbacks with the outer systemic layers (economy, society, planet) the power system will be influenced by the inequality misalignment and its evolution, with impacts ranging from achievable decarbonisation rates to governance capabilities. Power system organisational structures also contribute to the evolution of the inequality misalignment through other misalignments (see section 4.1 on the "grid death spiral" for more details) and its impact on energy poverty.

[65] The richest 1% alone were responsible for 15% of the 1990-2015 cumulative emissions.



IN FOCUS

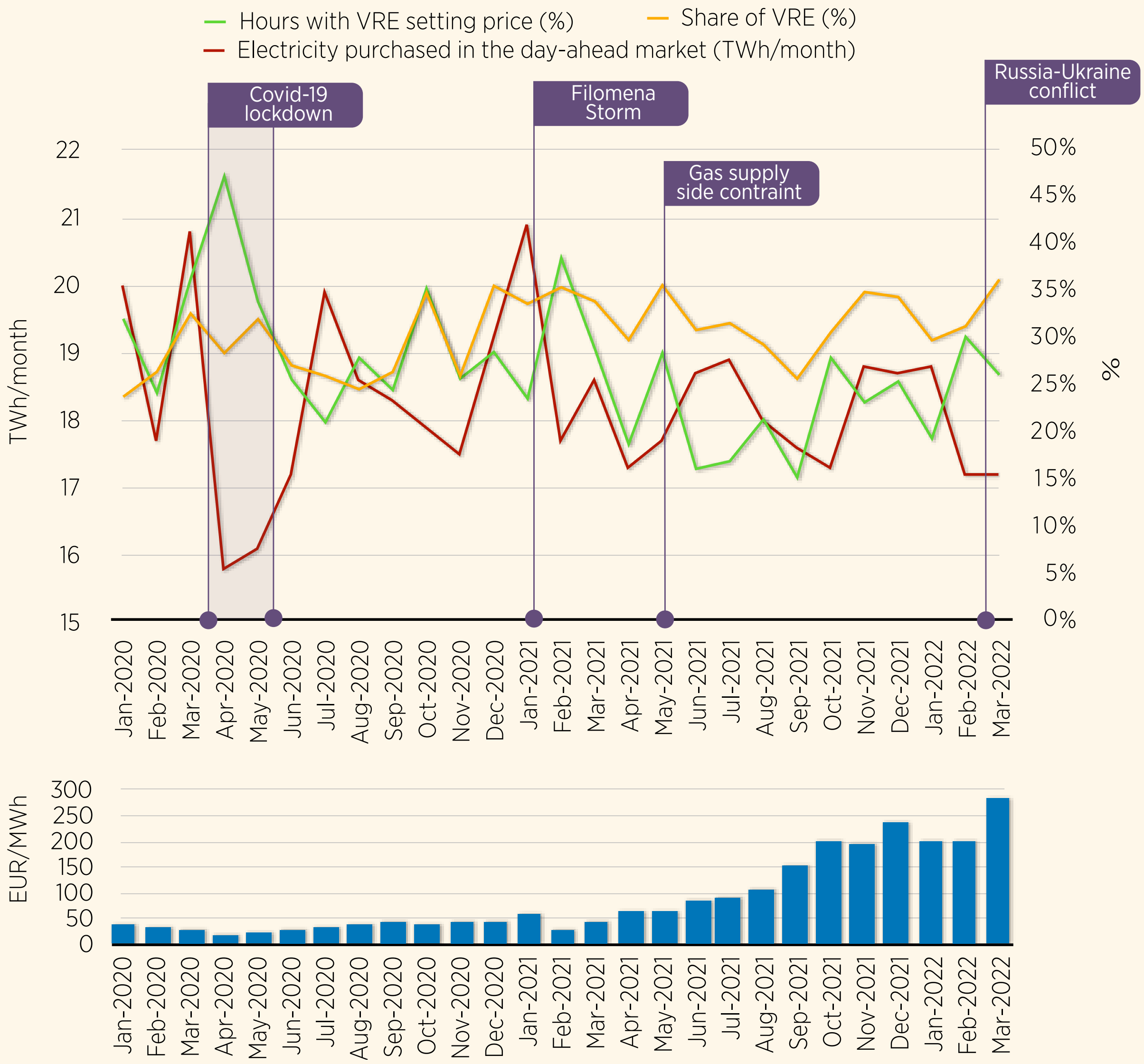
HIGHER VOLATILITY IN WHOLESALE MARKET PRICES AS THE ENERGY TRANSITION UNFOLDS. THE SPANISH CASE

As the energy transition unfolds, higher volatility in wholesale market electricity prices is becoming apparent. On the one hand, wholesale prices may spike driven by spikes in the price of natural gas and the role that this technology still has in setting the marginal electricity price in some power systems. Gas price fluctuations may be linked to the transition either directly (via CO_2 pricing) or indirectly (via mismatches in international gas markets). A slow transition delaying the phase-out of natural gas and its swift substitution with renewable energy and non-fossil flexibility will extend these events into the future.

On the other hand, extremely low (less than EUR 1/MWh) or even negative wholesale electricity prices have been already experienced when VRE production reaches high shares. The initial COVID-19 lockdowns intensified the occurrence of these events in systems with already significant VRE contribution because of the resulting reduced electricity demand. As the transition progresses, under current organizational structures, the increasing shares of VRE generation would make these extremely low price events more common.

These dynamics have already been playing out in the Iberian electricity wholesale market during 2020 and 2021 (Figure 31). Wholesale electricity prices declined during periods of high shares of hours when VRE cleared the market price, which in turn can be driven by low electricity demand (such as during the first COVID-19 lockdown - April 2020) and high shares of VRE generation (such as in February 2021). January and February 2021 provide another good example of these dynamics. The Filomena storm in January 2021 draw demand up, with a reduction of the number of hours when VRE cleared the market price, resulting in high prices. In February 2021 demand went down and VRE share up, with an increased number of hours when VRE cleared the market price, resulting in lower electricity prices (Figure-31). When gas prices increase and gas sets the marginal price (such as during the energy crunch triggered by supply side constraints from May 2021 onwards), wholesale electricity prices skyrocket.

FIGURE 31. **Monthly average cleared prices in day-ahead market, electricity demand, renewable energy share, and share of hours when VRE set the price in Iberia's wholesale market, 2020-2022**



Source: REE, 2022; OMIE, 2022.

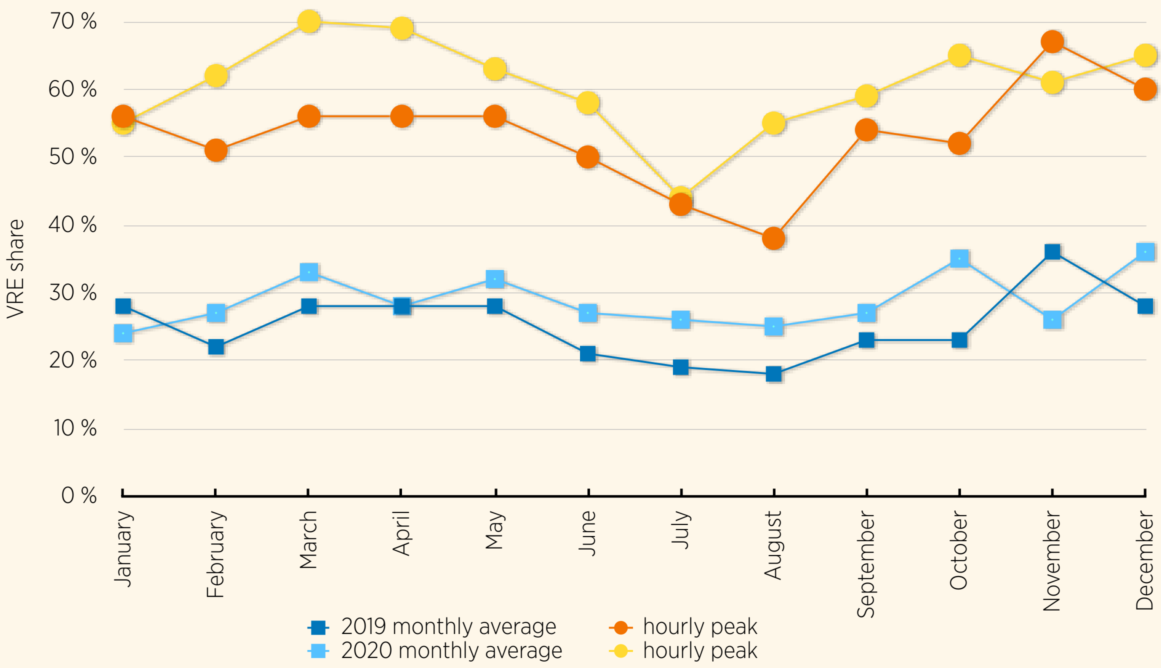
Low electricity prices during COVID-19 lockdown

The COVID-19 crisis provided a glimpse of the future with regard to the impact of increasing VRE participation on current wholesale markets. Whereas during the energy transition the increasing shares of VRE will be driven by increasing VRE capacity, during the pandemic they were a consequence of the decrease in demand; however, in relative terms the implications for the power system are similar: VRE generation is increasingly involved in setting the hourly marginal price in the wholesale market, driving down prices.

In Spain the majority of new renewable power plants since 2014 have been connected to the grid without any additional regulated payment, relying on the wholesale market to fully recover their costs (merchant renewable plants).

Between 9 March and 21 June 2020, a nation-wide lockdown was declared in response to the COVID-19 pandemic, with the stricter measures reducing economic activity and mobility enforced between 19 March and 11 May. Electricity demand dropped quickly with the confinement measures, down 15.7% on average in April 2020 compared to the previous five years. The lower electricity demand led to higher VRE shares than in former years, surpassing in several occasions the 2019 record during March and April 2020 (REE, 2022) (Figure 32).

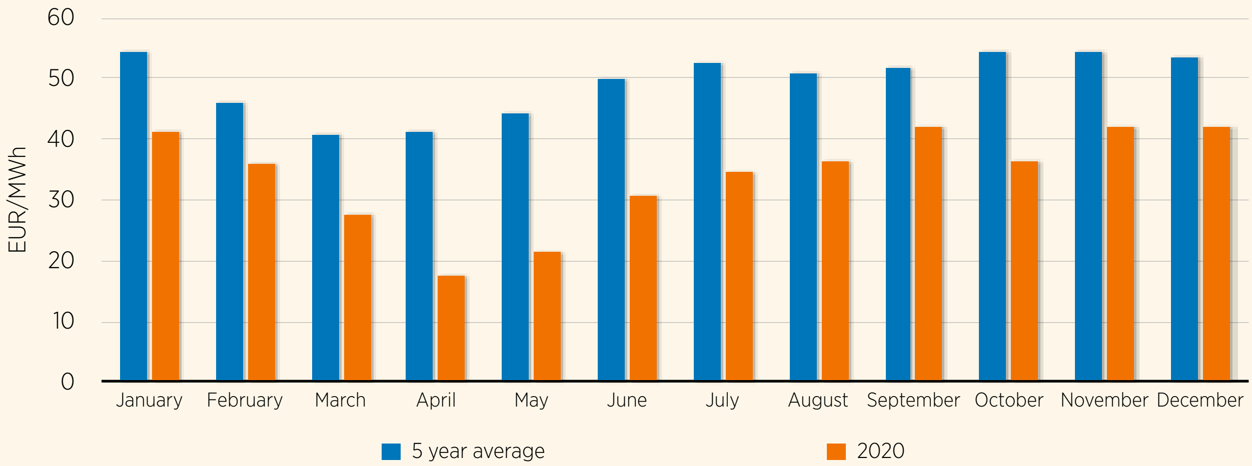
FIGURE 32. **Variable renewable energy average and hourly peak shares by month, 2019 versus 2020**



Source: REE, 2022.

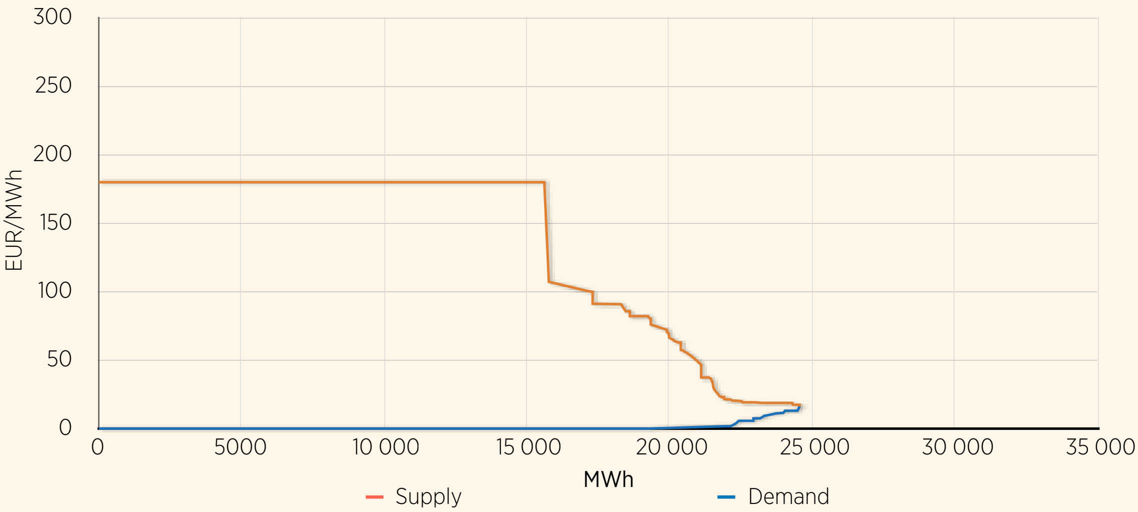
The COVID-19 induced drop in demand led to a substantial reduction in greenhouse gas emissions from the power system (-44.3% in April 2020) (REE, 2022). Despite similar shares of VRE generation that same month in 2019 (Figure 32), average monthly wholesale electricity prices also fell in April 2020 because of the higher share of hours when VRE set the marginal price during the month (Figure 31). The monthly average day-ahead clearing price in March 2020 was EUR 27.7/MWh (-27% compared to 2015-2019 average), in April was EUR 17.7/MWh (-57%) and in May was EUR 21.3/MWh (-52%) (Figure 33). Figure 35 shows the price formation curves for April 2020 at 12 p.m., when low demand and relatively large VRE generation pushed the price down to below EUR 20/MWh.

FIGURE 33. **Evolution of monthly wholesale market prices in Spain, 2020 versus previous five-year average**



Source: REE, 2022.

FIGURE 34. **Supply and demand curves in the wholesale power market in Spain, 12 p.m. on 16 April 2020**



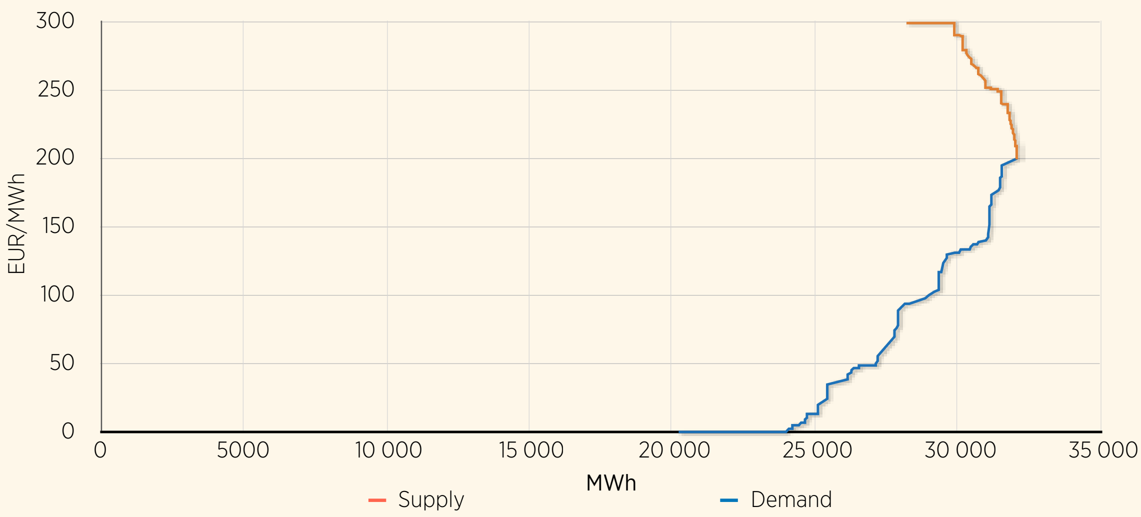
Source: OMIE, 2022.

High electricity prices during the energy crunch

In the summer of 2021, Europe and Asia experienced an energy crunch due to various factors that created a "perfect storm". At first, the post-COVID economic recovery increased the demand for energy in the power sector and recovering industries, particularly in the chemical sector. This happened during a hot summer (high air conditioning demand) with low wind power generation. Summer is also the season in the EU when natural gas reserves are filled to cope with winter demand. However, during summer 2021 the EU reserves were below the usual, prompting aggressive buying. At the same time, a shortage in gas supply due to political tensions and unexpected bottlenecks greatly contributed to increased gas prices.

Since electricity wholesale prices are set by marginal power plants, high costs of gas imply high electricity prices where and when gas sets the marginal price, even if VRE also contributes to cover the demand with very low marginal costs. Hence, with high gas prices and gas often setting the marginal price, users are being impacted by extra-high wholesale electricity prices (above EUR 200/MWh in many hours of 2021, reaching peaks of EUR 700/MWh in March 2022) due to the pricing mechanism of the power system. For example, at 12 p.m. on 18 November low marginal cost plants provided around 24 GWh (75% of the demand), but to cover the remaining 8 GWh, other plants had to be activated, with natural gas setting the marginal price at EUR 200/MWh for this hour (Figure 35).

FIGURE 35. Supply and demand curves in the wholesale power market in Spain, 12 p.m. on 18 November 2021



Source: OMIE, 2022.

It should be noted that under the current marginal pricing structure, high wholesale clearing prices occur more often than the instances when natural gas fueled technologies directly produce these high prices by clearing the market themselves. Indeed, the high natural gas prices indirectly impact wholesale clearing prices through the bidding behavior of other dispatchable technologies, such as hydro power. Hydro power plants are very aware of the natural gas powered plant bids (often are operated by the same utility), and hence have the incentive to bid with an opportunity cost just below the natural gas bid. Therefore, high wholesale electricity prices may also result even when natural gas plants are not the clearing technology.

If VRE power plants were not receiving the wholesale price (merchant plants), but a long-term payment agreed beforehand, the overall electricity price under events such as that shown in Figure 35 would be significantly lower, since only a small fraction of overall generation would be rewarded at this high marginal price. However, the required long term payment for VRE is higher than the low marginal cost bids that VRE provides to the wholesale market (Figure 34), since it needs to cover its life-cycle costs and profit goals. It is important to note that under the current wholesale market structure, infra-marginal plants, count on the difference between its marginal costs and the cleared price to recover its CAPEX and to generate profits. Moreover, this difference is the main economic signal to encourage investment in a liberalized context. It is the overall life-time retribution to renewable energy generation and its certainty for investors that will determine its feasibility and make it possible to reap the benefit from its potential low generating costs (keeping finance costs low).

Lessons from the Spanish experience

The extraordinary volatility in wholesale market electricity prices in Spain during the COVID-19 pandemic and the 2021 energy crunch illustrates the impact from some of the wholesale market misalignments discussed in chapter 4. To properly steer the transition it is crucial to become aware of the strong systemic interactions at play between the power, energy, economy and social layers. The high volatility in electricity prices may trigger strong social reactions. Policy action in response to high prices and the associated social concern may introduce quick fixes which by missing the overall picture (its balance with the low price events) produce transition barriers, ultimately hindering the required deployment of renewables and flexibility.

Indeed, during the second half of 2021, many EU Member States felt pressure from their populations to react with measures that deliver short-term results in order to alleviate the burden of high electricity prices on households and companies during the COVID-19 recovery. Without a long-term vision, some of those measures risk producing additional barriers to transition. A holistic approach is needed to make power system organisational structures appropriate for the energy transition and for a renewable-based power system.

The time is ripe to holistically address the re-design of power system organisational structures.

Aerial view of solar panels, Andalusia, Shutterstock

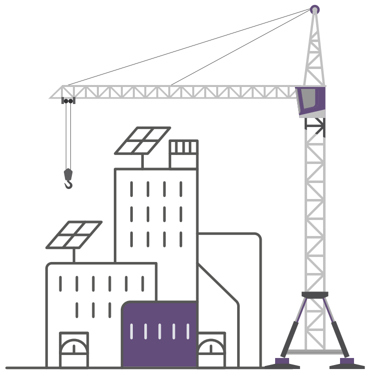
5 THE ROLE OF MARKETS: ENABLERS OR BARRIERS?

The existing power system organisational structures were conceived and put in place long before the energy transition was globally accepted as a necessity. They are the result of a process of adaptation to the technological and cultural changes that happened in the past in the power sector.

VIUs were the norm before the 1990s, which was consistent with grid expansion needs and, in many countries, with post-World War II reconstruction efforts, taking advantage of economies of scale and focused development through central planning.

In the more recent past, during the last three decades, a sustained global effort has been deployed to induce liberalisation in power systems across the globe, promoting market-based, profit-driven competition procurement and allocation mechanisms in formerly public, centrally planned and vertically integrated systems (see chapter 3). In recent decades, liberalisation has been considered the preferred pathway to introduce economic efficiency in most sectors, including power systems, with the final goal of benefiting users by reducing prices and their share of risks. Nevertheless, in practice, liberalisation reforms of power systems proved difficult to apply universally, leading to a wide range of hybrid solutions between liberalised and regulated systems (Box 19).

The drivers that in the past led to the predominance of regulated systems are gaining traction today as the transition progresses and socio-economic challenges are addressed.



Interestingly, the drivers that in the past led to the predominance of regulated systems (intense grid expansion needs and a reconstruction context) are gaining traction today as the transition progresses and socio-economic challenges are addressed. Many countries in the Global South still face very important grid expansion needs, which will increase as their populations progress along the electricity access ladder. Even in Global North countries, the energy transition imposes additional grid expansion needs, because of both the increasing electrification of energy services and the need to integrate renewable generation and flexibility resources. The unfolding climate crisis and the recovery imperatives from the pandemic provide a context of urgency and reconstruction (IRENA, 2020d), where large-scale and highly co-ordinated means of production and allocation seem to have a role to play.

An analysis of the history of power system organisational structures seems to point to the fact that, in the current context, both regulated and liberalised components may have space to contribute to the transition and to address current challenges. Therefore, it seems worthwhile to revisit the thinking (inherited from the recent past) that considers liberalisation (markets) as the only way forward, and to search also for synergic combinations of liberalisation and regulation that can deliver for the challenges ahead in different socio-economic contexts.

Already, the energy transition is producing a hybridisation of structures, such as regulated support for renewable power in liberalised systems and competitive procurement of renewable power in regulated systems (Roques and Finon, 2017).

Addressing the climate emergency and the biodiversity and inequality challenges requires societies taking action collectively and with this common purpose (collaboratively). Therefore, beyond the regulation and competition components, organisational structures must address how to incorporate a third component: collaboration to accelerate the energy transition without leaving anyone behind.

This section explores the role that competitive markets may play in future power system organisational structures, discussing under which circumstances these can be enablers or barriers for the needed energy transition, and exploring its appropriate mix with the regulative and collaborative components.

5.1. PRE-TRANSITION LEARNINGS ABOUT MARKETS IN POWER SYSTEMS

The electricity sector reforms that started in the 1990s were framed under a general trend towards privatisation of the economy in the pursuit of better economic performance. Liberalisation in the power sector, as in the wider economy, was based on the idea that the combination of competition, profit maximisation and strong incentives for managerial alignment with the profit maximisation goal would improve the economic efficiency of utility operations (World Bank, 1993). At that time, many VIUs often suffered from social disaffection, as they were struggling to get rid of the burden of excessively bureaucratic management and had decision-making processes with scarce public accountability and high vulnerability to political instability. This created a favourable environment to weaken socio-political resistance to liberalisation in the power sector and, similarly, in many other public services such as water supply, rail transport or health services. International institutions often reinforced the trend towards liberalisation, especially in developing countries, by dictating it as a pre-requisite to access international support or finance (Chang, 2010).

FIGURE 36. **Competitive components in power system organisational structures**

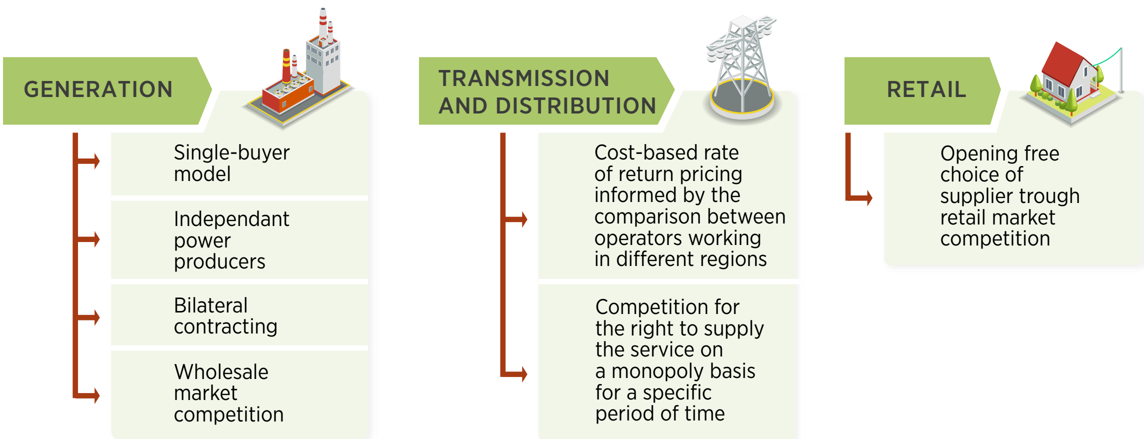
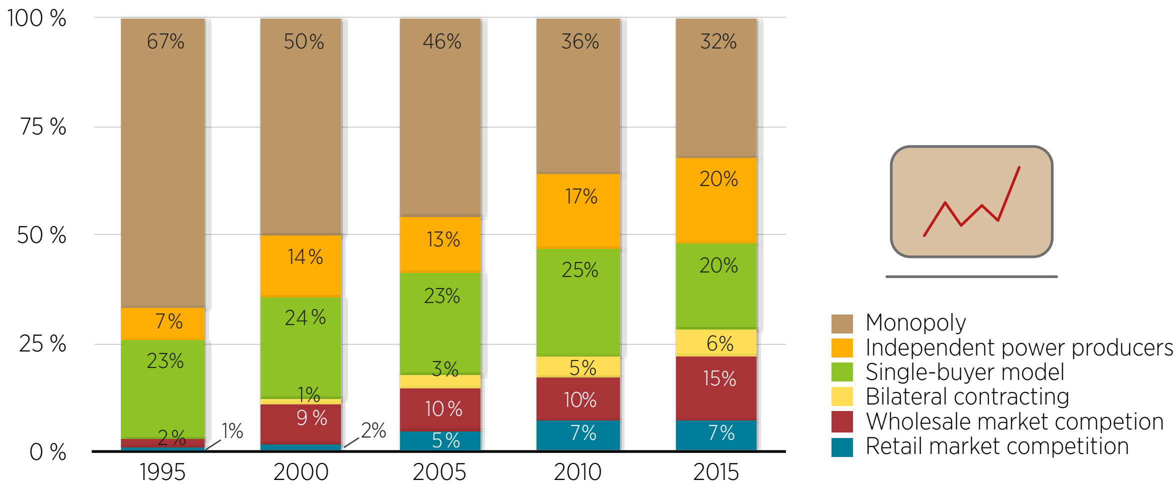


Figure 36 illustrates possible ways to introduce competition in each of the power system segments. Liberalisation prescriptions in the power sector included vertical and horizontal unbundling (see chapter 3), the creation of independent energy regulators, and the introduction of competition among corporate providers. Competition among private firms has first been introduced in the generation segment, where firms provide services (IPPs, single buyer model and bilateral contracting) to a VIU that also manages its own generation assets. Subsequent progress along the competition ladder involves eliminating the utility and establishing bid-based wholesale markets where all generators compete to provide the energy service to the system; as well as the introduction of retail markets where retailers compete to provide the best cost/service combination for each user. In a few cases, the introduction of competition has also reached distribution and transport activities, getting different firms to contend for the right to supply the service for a specific period of time (Foster and Rana, 2020; Steiner, 2000). However, since most power systems today do not have competitive components in the transmission and distribution segments, these are not further addressed in this report.

Today, most countries have some or all of these competitive components in their power system organisational structures. However, the progress of these components, although high in the Global North, has been limited in the Global South (Figure 37). Between 2000 and 2015, the rate at which developing countries introduced competitive components into their organisational structures was low: 40% of developing countries stopped their progress towards liberalisation at the very early stages with the introduction of IPPs in a monopolistic environment or the single buyer model. Competition in transport and distribution segments has been quite rare. However, countries that had already launched significant measures to introduce competition by 2005 have generally completed this process and gone all the way to retail competition by 2015 (Foster and Rana, 2020). Only three countries (Albania, Bolivia and Burkina Faso) reversed the introduction of competitive components (Foster *et al.*, 2017).

FIGURE 37. Evolution of competition elements in developing countries' power sectors

Only one in five developing countries has established a wholesale market
and less than one in ten has a retail market.



Definitions: 1. Monopoly: a single company responsible for generation, transmission, distribution and retail sales; 2. Independent power producer: as previous, but in addition, private IPPs can compete for the right to generate a share of the produced electricity; 3. Single buyer model: one single wholesale power trader, with no direct interest in generation, that purchases power from all generators, and sells it to distributors and large wholesale customers; 4. Bilateral contracting: a single buyer of power trades power for the majority of retail customers, while allowing large users to purchase power directly from various generators; 5. Wholesale market competition: a power market of multiple generation firms trading directly with multiple distribution companies and other large users, assisted by an independent system operator and market operator. Small users can buy only from their local distribution system operator 6. Retail market competition: as previous, but allowing all users (small and big) to purchase power directly from retail companies. It requires previous vertical unbundling of distribution and retail companies, with distribution system operators providing open access to the grid and providing services to multiple power retailers.

The country database includes 88 developing countries. The complete set can be found in Foster *et al*. (2017).
Source: Foster and Rana, 2020.

After a few decades of introducing competition in power systems, the move towards liberalisation has resulted in significant diversity across countries in the timing, approach and accomplishment of reforms (Box 20). Today, a wide range of hybrid organisational structures exist, especially in the Global South, between the two extremes of almost fully liberalised, unbundled, corporate-owned power systems, and centrally planned, vertically integrated and publicly owned ones.

Box 20. Adoption of power system liberalisation reform at the global level

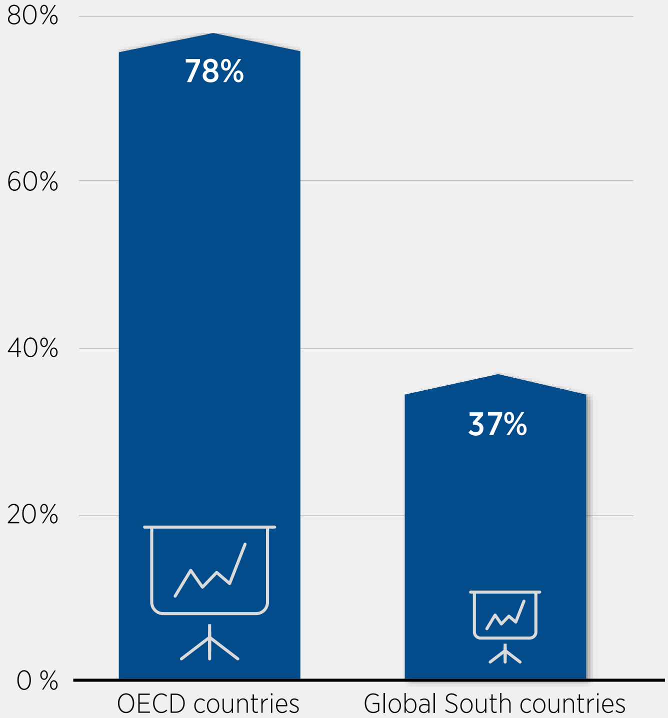
Expectations of power system liberalisation were high in the 1990s, including the creation of an independent regulator, vertical and horizontal unbundling (restructuring), the introduction of the private sector in distribution, generation, and retail, and the introduction of competition in procurement mechanisms, notably generation and retail. However, after almost 30 years its adoption is far from universal. According to the Power Sector Reform Index* used by the World Bank, whereas member countries of the Organisation for Economic Co-operation and Development (OECD) have embraced on average 78% of the reform policy indications of the 1990s, the extent of assimilation in the Global South is only 37% (Foster and Rana, 2020) (Figure 38).

Scarcely a dozen developing countries have completed the full liberalisation reform*, while most have adopted a model that combines some features of competition with continued state dominance of the sector (Gratwick and Eberhard, 2008). Many small, low-income states (representing a quarter of developing countries) have just marginally initiated reforms of their power systems.

Despite the greater advance of power sector liberalisation reform in OECD countries, even here its adoption is not complete. VIUs persist in some countries such as Japan and the Republic of Korea, where vertical integration preference is not limited to the power sector. In other cases, the extent of privatisation is limited, such as in France where most of generation, transmission and distribution is state-owned (Foster *et al.*, 2017).

Research shows that the progress of liberalisation reforms depends on each country's starting socio-economic and political context. Liberalisation has advanced the most in middle- or high-income countries that have a supportive market-oriented political environment, and in relatively large power systems with a well-functioning framework of tariff regulation (Foster and Rana, 2020).

FIGURE 38. **Adoption of power sector liberalisation reform at the global level: Comparison between OECD and Global South countries on average**



Source: Foster and Rana, 2020.

* The toolbox of reforms prescribed by international donors in the 1990s for power sectors in developing countries included four main elements: restructuring (vertical and horizontal unbundling of power utilities), private sector participation, setting up of an independent regulator and introducing competition in generation. A simple Power Sector Reform Index has been constructed by Foster and Rana (2020) to evaluate the adoption of the four dimensions of power sector reform considered. The index gives each country a score from 0 to 100 on each dimension of reform, and the average of the four scores provides an overall summary of the uptake of liberalisation. A higher score merely indicates that more reform measures were taken; it does not necessarily suggest a better power sector performance or organisational structure.

In theory, wholesale markets should provide appropriate price signals to guide production and investment decisions. However, for competitive wholesale markets to work properly a series of demanding pre-requisites are needed in terms of governance and enabling participation. Fulfilling these pre-requisites has proved to be challenging[66] (Besant-Jones, 2006; Pollitt, 2012). To improve governance, the appropriate links also need to be established between wholesale markets and users of the energy service, providing the means for wholesale price signals to cascade down so that they can help guide users' decisions, and allow users' actions to influence producers' decisions.

Competition, together with independent regulators and good governance mechanisms in favourable socio-economic and political contexts, has improved the overall efficiency and financial viability of utilities, while facilitating a better environment for investment during the fossil fuel era (Goldeng, Grünfeld and Benito, 2008). However, even within the fossil fuel era, when profit-driven competition has been introduced with weaker starting conditions, it has seldom led to positive results, even increasing the risk for policy turnabout (Foster and Rana, 2020; Percebois and Wright, 2001; Pollitt, 2012; Yu and Pollitt, 2009).

Furthermore, several countries have shown that it is possible to achieve comparable power system performance without advancing the liberalisation agenda (Foster and Rana, 2020). Costa Rica and Uruguay are two cases in point, with competent state-owned vertically owned utilities guided by clear policy goals, combined with a more gradual and targeted role for the private sector (ICE, 2020; UTE, 2020). These systems have a result-oriented governance that aligns decision making, institutions, agents and instruments (inside the power system and beyond) towards clear policy goals, responding to participation, transparency and accountability requirements. This approach has allowed regulated state-owned power systems to improve the operation of utilities while maintaining the ability to deal with the power system as a whole and to properly address wider socio-economic system interactions. Such an integrated approach offers advantages when addressing deep transformation requirements within limited time frames, such as the energy transition.

5.2. COULD COMPETITION CONSTRAIN TRANSITION GOALS?

Current organisational structures, with their different balances between central planification and profit-driven competition, represent the starting point for the energy transition in each country.

The role of competition is relevant not only for already liberalised systems but also for regulated and hybrid systems that are exploring the role it should play in the evolution of their organisational structures. Most of the world's future population will be in Africa and Asia (Vollset *et al.*, 2020), two continents currently dominated by regulated or hybrid power system organisational structures.

Transforming power system structures can be a long and challenging process, as proved by experiences with the attempted liberalisation reform. To facilitate the energy transition and prevent barriers, power system organisational structures should evolve with anticipation. Unfortunately, they often lag behind, reacting with fixes to the upcoming challenges instead of anticipating them. The pros and cons of profit-driven competition in the context of the energy transition are addressed in the following sections, with specific attention to the roles of governance, generation and retail.

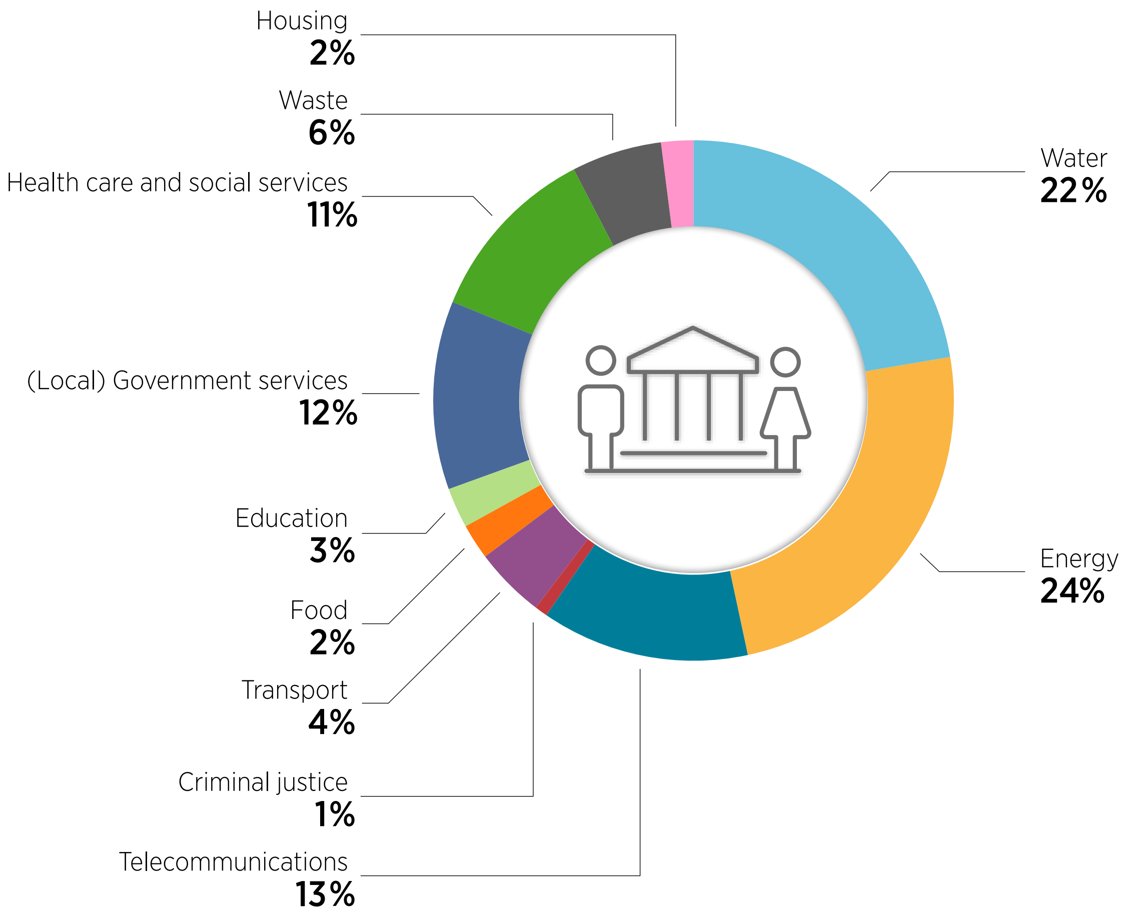
[66] Among others, these pre-requisites include a sufficient pool of market participants, lack of unequal power position by individual participants, and lack of restraints to access the market and enable participation.

The role of governance and ownership structure

Even the best structured markets have been unable to deliver on social and environmental imperatives (energy access, long-term renewable energy investment, fossil fuel phase-out, etc.). As in regulated environments, additional policy measures have been essential to redirect and promote the needed investments for energy access and the energy transition (Foster and Rana, 2020). Shifting the spirit of the power sector from one of public service to one of short-term profit maximisation can be at odds when it comes to accomplishing long-term goals such as granting energy access and achieving resilience while undertaking a rapid, just and fair energy transition (Thomas, 2004; Weghmann, 2019). The complexity involved in achieving the desired socio-economic outcomes with the existing local pre-conditions challenges the idea of markets being the only possible organisational structures for the energy transition.

The privatisation dilemma is not exclusive to the power sector. Other sectors dealing with vital services have been confronted with opposing arguments regarding profit-driven organisational structures, especially when socio-economic changes are taking place (Box 21). Already more than 1 500 cases of (re)municipalisation of essential services have been mapped globally, following attempts to rebuild public capacity to provide local services as a direct response to existing challenges faced by privatised structures (Figure 39) (TNI, 2020). Motivations observed for de-privatisation measures in many sectors are diverse, but they often include reverting the inadequate performance of privatisation or the need to align the service provided with wider policy objectives (environmental, social or other).

FIGURE 39. **Cases of de-privatised public services mapped at the global level**



Source: TNI, 2020.

Box 21. Paris: Reverting more than 30 years of water management privatisation

From mid-1980 to 2010, the public water service of the French capital city (Paris) was provided by three entities: a joint venture in charge of water supply and two private corporations in charge of water distribution. Audits demonstrated that, as a result of this fragmented approach, water costs for users were 25-30% higher than under a more integrated approach. This went straight to the community's bills, with the price of drinking water increasing 7% annually on average during this period (DPIDG, 2014).

In 2007, the city began a process of taking over its public water service, creating a public authority, Eau de Paris, to take charge of the production and distribution of water. In 2010 (re)municipalisation was completed. As a result, tariffs dropped by 8%, some 1200 drinking water fountains were placed across the city, and aid was established for households that face difficulties paying their water, energy and housing bills. These activities responded to the public authority's commitment to treat water as a vital common good as opposed to a commodity (TNI, 2020).

To strengthen participation, the board of Eau de Paris is composed of elected municipal officials, staff representatives and members of water rights and environmental non-governmental organisations. This open governance, together with open public access to all key information about the water service and management, enables wide supervision of Eau de Paris' activities and decisions. In 2017, Eau de Paris received the United Nations Public Service Award, acknowledging its sustained effort in improving its accountability, transparency and integrity.

With escalating pressure to curb CO_2 emissions and increasing dissatisfaction with the operations of private utilities, political debates are gaining momentum[67] around the idea of whether state ownership of utilities (as a proxy for societal control) could be an appropriate way to accelerate the rate of energy transition while also delivering social resilience. Some countries have recently created new state-owned utilities, driven in part by the prospect that state-owned entities would make more climate-friendly investment decisions (Wollmann, Kopric and Marcou, 2016) (Box 22).

[67] This was the case, for instance, during the last UK election campaign and the US primary election campaign (Bade, 2020; Hodges, 2019).

Box 22. State ownership and renewable energy technology adoption: The case of the EU

In both privately owned and state-owned utilities, some investments do not respond to social demands (decarbonisation, energy access, etc.). Moreover, no systematic worldwide evaluation is available on the link between ownership models and pro-activity in the adoption of renewable energy technologies. However, Steffen *et al.* (2020) studied the generation investment decisions of both privately owned and state-owned utilities in the EU* during 2005-2016. Results suggest that, under the same policy environment, state-owned utilities devoted higher shares of investments to (non-hydropower) renewables compared to privately owned utilities. However, state ownership does not exert its influence in a vacuum: it interacts with the existence of pro-adoption policies and state enforcement capabilities.

For instance, Belgian state-owned utilities, between 2005 and 2016, devoted 79% of their total investment in generation to (non-hydropower) renewable energy, whereas private firms dedicated 51%. In the Czech Republic, no private firms invested in renewable energy capacity additions above 1 MW between 2005 and 2016, whereas state-owned utilities devoted 92% of their investment to renewable generation during the same period. An exception is Italy, where private corporations dedicated 20% of generation investments to renewable energy, but public utilities dedicated only 2%, with the resulting private absolute investment being higher than the public one.

The higher propensity of state-owned utilities to invest in renewables seems to be the result of a more favourable interaction between support policies and the governments' influence on their utilities to properly use these favourable circumstances, although other factors could also play a role.

*All EU Member States retain one or more state-owned utilities, except Luxembourg and Spain. Examples include the Swedish public utility Vattenfall and the Public Power Corporation of Greece.

Private project developers have opened the space for new renewable energy technologies in a number of countries (Steffen, B. *et al.*, 2018). However, now that renewable technologies have proven their maturity, large incumbent utilities (be they private or public) are important in scaling up the adoption of renewables across the world. At this stage, and when conducive policy and governance environments are in place, state ownership becomes as an option worth considering to align utilities' technological choices with transition requirements.

Where state ownership exists, policy makers can strategically take advantage of this ownership structure to advance in achieving climate targets (Steffen, Karplus and Schmidt, 2020). However, this requires stringent governance measures both on the policy side and in utility operations, with social participation and support being key to achieve efficiency and economic sustainability.

In practice, neither public vertically owned utilities nor liberalised competitive systems are socio-economically efficient and sustainable by default. Both can be captured by bureaucracy and inefficiency, by vested interests and even by corruption. Thus, whatever the chosen pathway (public ownership or liberalised), a successful transition depends on strong, high-quality regulation and governance. Governance, in turn, requires advanced forms of social participation where society can directly and indirectly participate in decision making.

Some of the benefits and possible limits related to the ownership regime of power systems are summarised in Table 1.

TABLE 1. Potential benefits and challenges of publicly owned regulated power systems and privately owned liberalised power systems

	BENEFITS	CHALLENGES
PUBLICLY OWNED REGULATED POWER SYSTEM	•Easier to address electricity supply as a public service. •Easier to implement mandates for universal access. •Easier to implement mandates for achieving climate and energy goals. •Increased capability to scale up transition rates (better crisis response capabilities).	•Possible economic inefficiency burdening taxpayers and/or electricity users. •In absence of good governance, higher inertia to introduce changes in advance to full blown-up crisis periods (lack of anticipation). •Risk of "regulatory capture". •Potential institutional power abuse. •High vulnerability to political instability.
PRIVATELY OWNED LIBERALISED POWER SYSTEM	•Private stakeholders stimulated to deliver economic efficiency. •Risks of "wrong business decisions" are, in theory, born by shareholders alone (reduced risk for users). •Oriented to cost compression. •Niche private actors can be early adopters of new technologies and hence accelerate change in first stages of transformation (anticipation).	•Higher inclination and room to externalise social and environmental impacts. •Market misalignments with social goals and protective environment for corporate activity may burden taxpayers with economic inefficiencies (bail out, regulation costs, etc.). •Private stakeholders not stimulated to deliver social optimum. •Slower response to crisis situations, with economic inertias linked to investment recovery slowing down transformation rates. •Competitive organisational structures difficult to implement universally. •Potential corporate power abuse.

Generation: The case of long-term procurement

Long-term procurement is always needed for system adequacy. But in a transition context, when the system infrastructure is being refurbished, it becomes even more crucial.

Wholesale markets, when designed to be energy-only markets, focus on short-term procurement and depend on indirect price signals to spur the required long-term investments, with power system adequacy hinging on these.

Long-term competitive procurement (of renewable energy) has been introduced in many countries with the aim of minimising public expenditure to support the transition in both regulated and liberalised systems (IRENA, 2019b).

The different competitive procurement mechanisms to guarantee generation in the long term can be classified in two main groups: 1) procuring electricity via an IPP that builds, owns and operates the power plants (in both liberalised and regulated environments), mainly through auctioned PPAs; and 2) procuring power plants through competitive EPC (engineering, procurement and construction) bidding processes, with the power plants being operated either by the VIU or by independent operators that can be competitively selected.

PPA auctions and EPC tendering present analogies and differences. Both cases open the generation segment to new entrants (be they generators or constructors), and both allow new technologies to emerge within systems dominated by traditional actors and the generation technologies that they master. Also, both schemes provide means to control the rate of renewable capacity deployment and, therefore, its cost. The main difference between the IPP and EPC approaches lies in the risk allocation to the different stakeholders.

PPA auctions allocate a higher share of the risks on the private counterpart, which finances and procures[68] the power plant, operating it to recover the upfront investment plus the benefit margin along the plant's lifetime.

EPC tendering, in contrast, allocates a higher share of the risks to VIUs, which have to finance and procure the power plant. In exchange, if properly articulated it allows the utility to better tailor the plant's design and operation to the needs of the power system (especially relevant in a transition context). Long-term economic benefits and know-how arising from the procurement and operation of the plant remain with the utility, which can re-invest them in more renewable power plants that are better suited to system needs, or contribute to the national fiscal budget in case of need. This allows better adjustment of profit margins and its balance with social benefits. The EPC approach also provides more room to enhance technological localisation, which in turn can facilitate the transition and allow for increasing local socio-economic benefits.

An additional risk, common to both PPA auctions and direct public investment, is that of the uncertainty in electricity demand and technological evolution estimates. Under both long-term procurement options these estimates are done by the regulator/government, and hence risks are directly passed to final users. In a fully liberalised context, merchant plants in theory would assume a bigger share of this risk, but only as long as misalignments are properly addressed and appropriate governance is in place.

[68] IPPs contract an EPC firm for constructing the power plant, and hence undertake all the EPC management risk.

Solar farm, Sevilla, Shutterstock

However, when competition is purely based on price minimisation it risks reducing the social value of renewables deployment. In PPA auctions it often displaces smaller actors (which are not able to access economies of scale or cheap financing) (Fell, 2017; Grashof, 2019; IRENA Coalition for Action 2020). This results in a reduced diversification in terms of direct beneficiaries (Hermann and Flecker, 2009) and triggers power dynamics that, in turn, may induce higher system and social costs because of under-building, delayed projects, sub-optimal technological and geographical diversification, lower stimulus to pay attention to local environmental issues and lack of societal involvement.

On the contrary, stable and accessible allocation mechanisms with straightforward rules adapted to all users, such as regulated feed-in tariffs and net billing schemes, tend to lead to increased participation and higher social acceptance because they involve households, small and medium-sized businesses, communities, energy co-operatives and municipalities (Bayer, Schäuble and Ferrari, 2016; Fell, 2017; Kahl, Kahles and Müller, 2014).

Similar issues can arise in the tendering of EPC contracts by VIUs. When tenders are based purely on price minimisation, they incentivise investment in large-scale plants of the cheapest technology located in regions with optimum renewable resources, excluding local companies and disregarding societal involvement, and not paying due attention to local environmental and socio-economic issues.

Hence, for both the IPP and EPC competitive approaches to deliver in the social dimension, good governance needs to be in place.

At the global scale, competition is helping to drive down the cost of renewables and storage technology, making the energy transition increasingly cheaper (IRENA, 2020a). However, a narrow focus on price minimisation leads to an uneven distribution of the potential transition benefits, triggering extractive dynamics with negative social and environmental impacts (*e.g.* degraded employment conditions and ecosystem impacts). Additionally, under existing international trade agreements, measures intended to maximise the local socio-economic benefits of the transition may be rejected as "protectionist measures" (Hajdukiewicz and Bożena, 2020).

Hence, although competition can potentially bring value to the long-term procurement of renewable generation in both liberalised and centrally planned systems, good governance is a must to reap these benefits. When based on collaborative, open, transparent and society-wide participatory processes, long-term procurement mechanisms can be more accessible, stable and balanced, improving social participation dynamics and fostering transition benefits for local economies (Box 23).

Box 23. Keys and challenges for social value creation with renewable power plant deployment

The deployment of renewable power plants offers the potential to create socio-economic value in local communities. However, reaping these potential benefits depends on proper and holistic management of the technology, social and policy dimensions. Meaningful participation of local communities in the planning, deployment and operation of renewable power plants is essential to drive social support, avoiding distrust in these projects and in the energy transition in general.

Emvelo, a South African company, has set the social goal of unlocking "green economy" opportunities in rural areas, thereby reversing current urban-rural migration trends. Emvelo's experience provides insights on how to reap the potential for social value beyond formal compliance with legal requirements. It also highlights the extreme relevance of appropriate and stable policy frameworks and energy planning in maximising social value creation.

In 2009, in the aftermath of the economic crisis, Emvelo began activities to deploy a Concentrating Solar Power (CSP) plant in Upilanga Karoshoek Solar Park in the Northern Cape, a province endowed with very good direct normal irradiation (DNI), the solar resource used by CSP plants. CSP has high socio-economic value for the province because of 1) its high potential for localisation (a big share of the plant components were linked to skills and supply chains already developed for other industries such as civil works and piping) and 2) familiarity of the South African power system with thermal power plants (which have many components common with CSP technology). Moreover, CSP with thermal storage is a dispatchable renewable power plant, contributing to the flexibility needed to enable the integration of other non-dispatchable renewable power plants.

The resulting plant, Ilanga-1, is a 100 MW CSP plant with thermal storage and is the first operational CSP project developed by Emvelo. Project development started in 2009, before South Africa's Renewable Energy Independent Power Producer Procurement Programme (REIPPPP*) was in place, with a strong focus on local community involvement. The REIPPPP provided a legal framework to introduce requirements for IPP projects to promote local socio-economic development. Bids were weighted 70% on the basis of price and 30% on social elements of the presented project (IRENA, 2019b). In 2011, the first window of the REIPPPP took place. However, due to administrative hurdles the Ilanga-1 project did not participate in the REIPPPP until the third bidding window (2013).

Emvelo focused on going beyond the minimum legal socio-economic requirements set by the REIPPPP and aimed to reap the full potential social value of CSP technology by addressing the following dimensions:

- Jobs: maximising the local and national workforce during construction as well as operations and maintenance (O&M).
- Supply chains: preparing local economic entities to have the capability to provide services and products.
- Management: maintaining local involvement in planning, construction and operation, to guarantee that development truly delivered on the planned social goals.
- Ownership: Fostering local and community ownership of the power plant through equity participation, both in construction and O&M.

The Ilanga-1 plant has 80% local equity shareholders (the original goal was 100%, but lenders requested the international EPC firms to take a 20% equity stake). Among the local equity shareholders, the host community holds

15% equity through a community trust established by Emvelo (higher than the minimum mandatory 5% under the REIPPPP), with dividend flows from the first day of operation. While the loan is being repaid, 90% of community dividends go to lenders and 10% to the community; once the loan is repaid (after 16 years of operation), 100% of community dividends will flow to the community. This dividend flow scheme, together with the legally mandatory 1% over the plant's electricity sales, has a positive economic impact on local communities, which can undertake meaningful projects from the start of plant operation. Most projects share dividends with communities only once the initial loan has been repaid (normally after 12 to 16 years). This delay in receiving dividends can create resentment in communities, reducing project acceptance and communities' willingness to support future projects.

Beyond that, the host community has been involved in the development, construction and operations of Ilanga-1, with regular stakeholder engagement meetings from the early stages: the social team met once a month with community groups, and every quarter a "leadership meeting" took place between high-level host community representatives, the mayor of Upington and Ilanga-1 developers to provide feedback and solve any challenges. The holistic focus on community interests, as opposed to establishing personal relations with a few local leaders, resulted in improved transparency and governance.

Ilanga-1 was also the first CSP project in South Africa where a South African developer (Emvelo) was a 20% shareholder in the construction phase, assuming managing responsibilities. This provided the integration and space to build local capacity and effective skills and know-how transfer from international EPC contractors, while at the same time boosting localisation efforts beyond the minimum bid requirements. Local enterprises were developed to supply basic services required by the project (transport, catering and other non-technical services).

Once the construction phase was completed, 93% of the staff directly employed during the three-year warranty period to operate and maintain the plant were South Africans, half of whom came from the local community within a 50 kilometre radius of the site, and were selected among the trainees who attended the first CSP Operations and Maintenance training course in Upington provided by the Ilanga-1 partners. After the completion of the warranty period, the partners have committed to gradually reach a 100% South African operations team.

Renewable energy project development involves complex social dynamics. Addressing these, and preventing them from becoming barriers for the project and the energy transition itself, requires improved governance with effective community participation. For the Ilanga-1 plant, the local partner (Emvelo) fostered community participation and governance well before the project's onset, undertaking pro-active steps to build trust and relationships with local communities. As a result, social unrest on-site was never experienced during project development, and union involvement during the construction phase was minimal in comparison to other renewable energy projects. Building trust with local communities requires a focused effort and a good track record from project inception through all project stages. Deploying this significant socio-cultural effort on a per-project basis may be inefficient: a stable pipeline of projects supported by political certainty would greatly improve the process by unlocking synergies.

A significant gap also may exist between auction design / project proposal and implementation. Explicit socio-economic goals in procurement processes are necessary but not sufficient. Administrative goals tend to set a framework to justify compliance with bare minimums. Potential gaps between post-ante justification and real implementation may arise, aggravated by limited monitoring of real results.

Materialising the theoretical social value stated on paper in the project proposal may be facilitated by continuous and direct active involvement of local partners in management of construction and operations, with a strong social focus to bridge the gaps between the contractor's development and construction teams as well as between locals and expatriates.

Localising a technology and providing socio-economic value to local communities requires far more than designing auction scheme requirements. True and lasting localisation requires good planning, stable regulation and policy, and appropriate implementation and follow-up.

Localisation bid requirements can easily be fulfilled on paper by, for instance, resorting to (usually urban) populations with the required skills that are residents of the country but located far from the site. This provides economic stimulus to the country but not necessarily to local communities and can introduce social dynamics that ultimately confront the local population with the project. Although outsourcing jobs can be appropriate for some services and tasks, for others, given appropriate planning, the local community can be involved to bring more localised socio-economic benefits.

Involving the local population in the localisation process requires identifying upstream and downstream opportunities. Planning and anticipation to train the local population is key, so that the community is ready when the project requires its participation. Localisation also requires providing stability of job opportunities and training progression. "Knee jerk" training can be more of a disruption than a real support for local socio-economic prosperity, since it leads individuals to invest time and effort in something that may not have continuity, potentially requiring them to start over after the project cycle is completed, wasting skills, training efforts and time.

Getting local supply chains working also requires continuity. Stimulating the local economy and developing local skills requires a predictable pipeline of projects supported by a sustainable and stable policy, so that workers from the community can find continuity in their training and professions and local companies can progress along the learning curve.

Emvelo is pursuing this continuity and sustainability despite significant hurdles. The follow-up project, Ilanga-2 (100 MW), was not awarded preferred bidder status in bid window 3.5 (2014) because of administrative barriers bid window 4 did not include CSP. For bid window 4.5 (2015), Emvelo presented three CSP plants (450 MW) for Northern Cape (Ilanga-3, Ilanga-4 and Ilanga Tower 1), but this bidding window was cancelled. Bidding windows 5 and 6 (2021) did not include CSP.

Emvelo is now exploring alternative approaches to the REIPPPP, such as bilateral contracts with private off-takers (mining companies) and the possibility of replacing baseload coal generation (1 600 MW) as currently envisaged under South Africa's 2030 Integrated Resource Plan (IRP).

The community engagement from Ilanga-1 is ongoing today, with a focus on improving social dynamics, providing local socio-economic value, empowering local communities to steer the transition towards sustainable economic activity, and serving as a basis for future project development at Upilanga Karoshoek Solar Park.

* REIPPPP is the auction-based support mechanism for renewable power deployment in South Africa.

Introducing competition in the retail sector

The energy transition is not only a supply-side story. It requires activating a wider spectrum of agents on both the supply and demand sides to provide renewable generation and flexibility. To maximise the system value, an appropriate balance between centralised and distributed assets will be needed. Clear signals to users are needed to induce adequate investment and to activate demand-side (centralised and distributed) services when needed.

Historically, in both liberalised and regulated systems, users' involvement in power system operation has been addressed through economic signals provided by retail rates or regulated supply tariffs. The design of economic signals is hence instrumental to foster favourable user behaviour with regard to producing, using and storing electricity, saving energy, adapting demand to VRE capabilities and increasing energy system electrification.

Retail rates (liberalised systems) and supply tariffs (regulated systems) are also the prevalent revenue stream for cost recovery in the power system and for the financial viability of utilities in most jurisdictions. While an excessive burden on users through their bills has negative socio-economic and welfare impacts, a misalignment between prices/tariffs and system costs can put at risk the financial viability of utilities or add further burden on national budgets in order to compensate the imbalance (hence detracting fiscal resources from other public spending).

In regulated systems, the VIU or the regulator is in charge of setting supply tariffs, whereas in liberalised unbundled systems, each retailer sets the retail prices offered to its users (incorporating the impact of the tariffs set by the regulator to cover regulated activities). Some level of regulated tariffs may co-exist in liberalised environments, especially in contexts where protection to (vulnerable) consumers is considered to be important (*e.g.* EU legislation).

Cost-reflective tariffs and fiscal sustainability are not a unique preserve of liberalised systems, nor does the liberalisation of the retail sector guarantee the non-intervention of public authorities in electricity prices. In the liberalised power systems of EU Member States, instances of electricity price intervention increased in 2019: 80% of Member States indicated that the protection of users was the reason for public intervention in price setting (ACER and CEER 2019).

Liberalisation of the retail sector was expected to improve the adherence of retail rates to cost recovery, while allowing users to choose the power retailer offering the price and service quality combination that best matches their needs. This goal has, to some degree, been achieved in some countries, mainly in the Global North (Jamasb, 2002). However, as a result of retail competition, some countries have experienced retail prices above those that would reflect the power system's costs. In other countries, inappropriate retail price design has prevented smaller users from enjoying the cost compression delivered by wholesale market competition.

Retail competition has often worked better for industrial and large commercial users than for residential and small commercial users, for whom benefits are often not so clear (Green, 2000; Joskow, 2003a). Supplying electricity to small users is relatively expensive for retailers, and these users do not seem particularly prone to switching their retailer. This low propensity to switch the retailer and their limited capacity to negotiate and control the retailer's performance, can result in small users in liberalised systems having to pay higher-than-needed prices for their electricity services, due to power dynamics (ACER and CEER, 2019).

Competing retailers were also expected to spark a wide portfolio of energy-related services beyond only supplying electricity, such as energy-as-a-service products (IRENA, 2020e), aggregation of distributed energy resources and other options to better meet individual user preferences (Joskow, 2003b). Competition opens the door to new entrants that tend to be more agile in adopting innovative approaches (Poplavskaya and de Vries, 2020).

For example, the embedded networks introduced in Australia facilitate retail rates that are more friendly to distributed energy resources within the jurisdiction of specific minigrids (see chapter 6). Another case is retailers offering dynamic pricing for electricity to users who choose so in the liberalised retail market. In Finland, for instance, some retailers offer price-optimised heating hours, on the basis of weather conditions and the heating capacity used, which may help save up to 15% on heating expenses (Eurelectric, 2017). However, the expectation of increasing the portfolio of offered energy services with value for users has not fully materialised, especially for small users.

Innovation related to demand response and the capability to provide additional energy-related services with value for users, however, are not a preserve of competitive environments. For example, New Zealand's system operator has been controlling demand since the 1950s, well before its liberalisation (MBIE, 2015). The system operator introduced hot water ripple control that allowed the electricity supply authorities (distribution system operators) to switch off customers' electric water heaters if required (Transpower, 2019). This is considered one of the first experiences in demand management (IRENA, 2019c).

Thus, while competition introduced in the retail segment of power systems can facilitate innovation diffusion leading to tariffs and services aligned with the transition, regulated vertically integrated systems also have the ability to directly scale up changes to support the transition with good co-ordination with other sectors (mobility, telecommunications, etc.) if appropriate governance is in place. Balancing the risks and advantages of exposing small electricity users to competition in retail pricing is an ongoing task that needs special attention.

5.3. TRANSCENDING COMPETITION THROUGH COLLABORATIVE APPROACHES

Beyond regulation and competition, organisational structures need to consider how to foster collaboration to accelerate the energy transition while maximising its socio-economic value.

Materialising the required collaborative[69] effort needed to address the climate crisis requires aligning everybody's efforts to curb emissions. Aligning efforts, in turn, requires building a framework of trust, where citizens perceive that good governance is in place, that no one will be left behind, and that the burden and benefits of the transition are fairly shared.

Fostering such a collaborative framework requires multiple ingredients including wider participation, improved governance, equilibrating the roles of production and demand, evolving market drivers from profit maximisation to social service, and confidence that resource use will be kept within planetary and social limits (Botsman and Rogers, 2011; Gansky, 2012).

[69] Collaboration and co-operation are terms that are often used interchangeably but that have distinct meanings. Collaboration refers to the activities of a group of agents that pursue a common goal. In this context, the goal is to complete the energy transition. Co-operation means that a group of agents agrees to contribute to the goal of a different group of agents. The difference between collaborative and co-operative projects, in other words, is ownership. The distributed character of renewable energy sources, energy savings and flexibility makes it possible for everybody to be involved and to own the energy transition goal, hence to collaborate for its accomplishment.

Collaboration can contribute to aligning the cost, price and value dimensions (see chapter 4) in both regulated and liberalised procurement of electricity and flexibility, preventing an unequal distribution of the benefits and burdens of the transition.

Collaboration can spark wider, effective and transparent participation in the power system, helping to align power structures and utilities' goals with social value creation. Facilitating collaboration across traditional knowledge boundaries by bridging multiple perspectives could provide innovation and better solutions than any of the institutions and actors would have reached by acting alone. Collaborative work on energy planning and policies of multiple disciplines across different groups of society can help secure the "best available knowledge" and allows a society-wide exchange on whether the different scenarios, plans or policies are both plausible and desirable from the perspective of different actors.

Collaboration can also ensure that resources are used within planetary limits by tapping into the potential for the power system to access shared resources such as storage, distributed energy resources, energy services, space, financing, time and skills, knowledge and data. Organisational structures are critical enablers to ensure that shared resources are allowed in electricity and flexibility procurement.

This section discusses some avenues for collaboration within power system organisational structures.

Collaboration to improve renewable energy and flexibility procurement

Undesirable distributive implications of profit-driven competition can erode the social value and acceptability of the energy transition, potentially becoming strong arguments against further ambition (Agora, 2020).

Fossil fuel phase-out plans induced either by market-based instruments (*e.g.* high CO_2 prices) or by regulation (*e.g.* power plant emission standards) can be disruptive for regions, countries and communities whose socio-economic structure is built around fossil fuels. In the EU, coal is still mined in 31 regions across 11 countries, with coal activities providing jobs to around 230 000 people. In this context, labour unions and local administrations of regions reliant on fossil fuels have acted many times in the past as barriers to transition, until a collaborative effort of unions, communities, utilities and administrations aiming for a just transition has been introduced (Prinz and Pegels, 2018).

Coal mining in an open pit, Shutterstock

To ensure that no region is left behind, the European Commission in 2017 launched the initiative for coal- and carbon-intensive regions in transition and recently introduced the Just Transition Mechanism, which provides technical, advisory and financial support to stakeholders (European Commission, 2020). The experiences in the Midlands of Ireland, Asturias in Spain and Karlovy Vary in the Czech Republic show that a key element of the collaborative effort to redirect phase-out plans towards a just transition is effectively engaging affected workers and communities in the design and implementation of a transition plan for the short and long terms. Co-ordination among different levels of administration has proven key for the process (European Commission, 2020), and collaboration among labour unions, administrations and corporations is another key element.

Recently, local opposition to rapid deployment of large-scale renewable energy technologies has gained momentum in several countries (Faucon, 2021). This has been triggered when host communities feel locked into an energy transition that reproduces traditional fossil fuel deployment dynamics, not taking into account local needs, participation and cultural heritage. Collaboration can prevent these situations, contributing to socio-economic value creation. Organisational structure components can be designed to foster collaboration. This often requires going beyond the strict system boundaries of the power system with a holistic vision. For example, renewable energy auctions in Spain already include the possibility to prioritise installation in just transition regions or to set up dedicated auctions for community energy projects. But collaboration with local actors beyond auctions is emerging as a key factor for preventing local opposition.

Citizen-led energy communities increasingly present themselves as a collaborative alternative to large, corporate-owned power plants, with community ownership and horizontal governance allowing locals to enjoy the benefits of the energy transition and to decide what to do with those benefits. Since the 1970s, local communities in Denmark have collectively invested in wind energy. The Danish 1996 Energy Plan aimed at creating an energy sector rooted in a "democratic, consumer-oriented structure". By 1996, the country was home to around 2 100 wind co-operatives, which created the basis for continuing social support for wind power in Denmark (IRENA, 2013). Since 2009, the Danish Renewable Energy Act has required a minimum quota of local ownership (at least 20%) in all new wind projects. The minimum quota was introduced as a roll-back from a previous policy framework that led to a significant decrease in community energy and thus also to social opposition. As a result, by 2013, 70-80% of existing wind turbines in Denmark involved community participation (Roberts, Bodman and Rybski, 2014).

In many cases, citizen-led energy communities reinvest part or all of the profits from their assets in new community-owned renewable energy plants or in supporting local social needs. In other cases, such as in Greece (Caramizaru and Uihlein, 2020), energy communities have reserved some participation quotas to distribute for free among vulnerable families, so that they can count on an extra income derived from the operation of the community-owned renewable plant.

Distributed energy resources facilitate direct user involvement. The energy transition can accelerate if users collaborate in financing, installing and operating distributed energy resources with the shared goal of maximising power system and social value. Aggregators can help co-ordinate this effort by merging users' distributed energy resources and operating them as a virtual power plant, providing valuable services to both distribution system operators and final users. Aggregators can work in both centrally planned and liberalised systems.

A competition-driven aggregator will tend to deliver its services guided fundamentally by the costs of distributed energy resources and the prices of flexibility services. In liberalised systems residential users are reluctant to get involved in virtual power plants for a wide range of reasons (inflexible retail rates, unclear policy framework, etc.), with profit-driven initiatives not having yet been able to properly align with users' needs and concerns. Community-based virtual power plants (cVPPs) facilitate the collaborative creation and operation of virtual power plants, reflecting the core values and needs agreed by all community members. Such cVPP community-based plants can already be found in Loenen (The Netherlands), Ghent (Belgium) and Ireland (Interreg North-West Europe, 2019). The identification of core principles is run through participatory processes and can range from maximising local clean energy supply and local benefits, to setting fair electricity prices, to creating local resilience (Van den Berghe, Baets and Meskens, 2019).

Collaboration can also directly aim at avoiding the exclusion of the most vulnerable from the benefits of distributed energy resources. A case in point is municipalities in Greece using the recently introduced Virtual Net Metering regulation to transfer renewable energy produced on municipal rooftops to vulnerable households (Box 24). Collaborative initiatives have also progressed in regulated systems. A case in point is the role that Costa Rican community-led co-operative distribution system operators played in advancing the country's energy access goal (Box 25).

Box 24. Surplus renewable electricity exchange and collaborative approaches to alleviate energy poverty

Retail rates conducive to community engagement in distributed energy resources, together with the support of not-for-profit interactions, may help address energy poverty and facilitate the inclusion of vulnerable households in the energy transition.

A case in point is European legislation that allows the surpluses of self-consumption facilities to be easily exchanged and allocated to the energy bill of other users located in nearby areas (virtual net metering / net billing). The price of the exchanged electricity can be arranged between the two parties except for the related grid costs that are regulated.

Several municipalities in Greece, for instance, are installing solar PV systems in public buildings for self-consumption and exchanging surplus production for free with vulnerable neighbours, as an alternative to subsidising energy consumption by directly paying the energy bills of vulnerable households.

These types of schemes allow progress in local collaborative initiatives aimed at sharing the potential benefits of renewable energy while tackling energy poverty and the climate crisis at once.

Frameworks to enable collaboration and a more direct involvement of citizens in the transition are progressing in different contexts. In the EU, the Clean Energy for All Europeans package adopted in 2019 provides the framework to foster energy communities to involve citizens and local public administrations in all aspects of the energy transition.

Box 25. Co-operation with community-led initiatives in regulated frameworks

Coopeguanacaste is a Costa Rican rural electricity co-operative located in the north-western region of Guanacaste. It was created in 1965 by local members with financial support and assistance from national government institutions (the national utility, Instituto Costarricense de Electricidad, and the National Bank of Costa Rica) to advance the national priority of full energy access. The co-operative was granted a concession to supply and distribute electricity within a certain area and illustrates a successful case of collaboration between a community-led initiative in a regulated environment and the national utility.

In 2015, Coopeguanacaste set up a solar PV programme for remote off-grid households (112 families), whereby it provides low-income families access to the generation from a PV system owned, managed and maintained by the co-operative as a subsidised social service. A one-time fixed installation fee and a monthly fixed rental fee are paid until the grid expansion reaches the household (Arias and Hernandez, 2014).

Over the years, Coopeguanacaste and other Costa Rican co-operatives have diversified their activities to generation with renewable energy, but further improvements of the collaborative framework are needed to better align with the national utility (Madriz-Vargas, 2018).

Collaboration to improve the ambition of energy transition planning

An instructive case of collaboration around ambition in a liberalised context relates to the EU consultation process around the Ten-Year Network Development Plan for Energy Infrastructures (TYNDP) scenarios, which the European Networks of Transmission System Operators (ENTSOs) prepare as a non-legally binding input for future electricity and gas grid expansion and grid modification projects in the region. For many years, European non-governmental organisations requested the ENTSOs to adapt the TYNDP scenarios to the Paris Agreement target and to disclose the underlying data and assumptions to enable transparency and effective social participation. In response, in 2018 a consortium launched the PAC (Paris Agreement Compatible Scenarios for Energy Infrastructure) project, which in 2019 delivered the first-ever scenario developed by civil society organisations through a bottom-up collaborative research process, involving more than 150 different stakeholders from member organisations, science and industry (PAC, 2020).

Thanks to the exchanges between the consortium and ENTSOs, the collaborative research process applied for the first time a carbon budget approach to the TYNDP 2020 scenarios (PAC, 2020). The approach sets a fixed cap on the amount of greenhouse gas emissions that the EU still could emit without putting at risk its commitment under the Paris Agreement. The modelling of TYNDP scenarios then aligns the foreseen evolution of the energy system with the chosen carbon budget. However, the size of carbon budget used by ENTSOs, which is the critical parameter defining the transition's ambition, was not agreed with the PAC counterparts.

Collaboration to share resources within power systems

Sharing knowledge and resources is an example where collaborative behaviour can positively influence the success of the energy transition. This section explores collaboration through sharing resources within the power system.

Sharing strategies can arise in both regulated and liberalised power systems and can involve three different actors: users, service providers and intermediaries between these. Resource sharing generally does not involve a change of ownership and can be carried out for profit or on a not-for-profit basis. Sharing resources, infrastructures and services represents an open field with multiple possibilities, with potential benefits for commercial and residential users, administrations and utilities.

Solar panel, Freepik

TABLE 2. Overview of sharing activities in the energy sector

ENERGY	SHARED GOOD OR SERVICE							
EXCHANGE MODEL	Material and energy	Products (re-distribution)	Product service system	Space	Financing	Time and skills	Knowledge and education	Data and information
UTILITY TO USER	Turnkey distributed energy resource or utility-scale projects	Second-life electric vehicle batteries for residential storage	Aggregation; cloud and district storage; embedded networks or minigrids	Parking places and charging stations for electric vehicles	Micro-credits for distributed energy resources	Consultancy and installation	Optimisation services	(Near) real-time data on users' production and demand; transparency services; neighbourhood platforms
USER TO USER	Peer-to-peer energy or storage trading and sharing; tool and appliance sharing; turnkey distributed energy resource or utility-scale projects via energy community or co-operative	Second life sale of batteries; collective purchase of appliances	Shared electric vehicles, smart heating and cooling systems or batteries; energy co-operatives/ communities; collective purchase of turnkey projects or appliances; collective contract negotiations	Roof or garage, basement space for computer used for blockchain data validation in peer-to-peer schemes, PV, micro-wind or batteries	Crowd-lending, -investment, -funding, digital currencies	Mutual support in energy co-operatives, energy communities or municipality-led energy initiatives; consultancy and installation through energy community or co-operative	Pro-user education; forums; energy education	Neighbourhood platforms; sharing platforms for exchanging sub-used goods, materials, tools and appliances
USER TO UTILITY	(Collective) storage; utility-scale or residential generation; virtual power plants or virtual lines (demand-side management, distributed energy resources)	Second-hand batteries for down-cycling	Collective purchases of appliances, power/energy or services	PV/storage leasing agreement; electric vehicle leasing agreements	Crowd-lending/-investment	Crowd-sourcing software	Smart home; feedback mechanisms; civic science; open innovation, open production, lead user innovation, co-creation	Advanced forecasting; civic science; swarm data storage
UTILITY TO UTILITY	Industrial symbiosis	Recycling of PV/ batteries; re-powering of power plants	Virtual power plants; asset pooling	Shared energy storage; complementary use of grids	Venture capital and micro-funding	Shared services; competence centres; white labels	Learning networks; joint research and development	Monitoring tools; energy data access (hub/ decentralised databases)

Adapted from Plewnia, 2019.

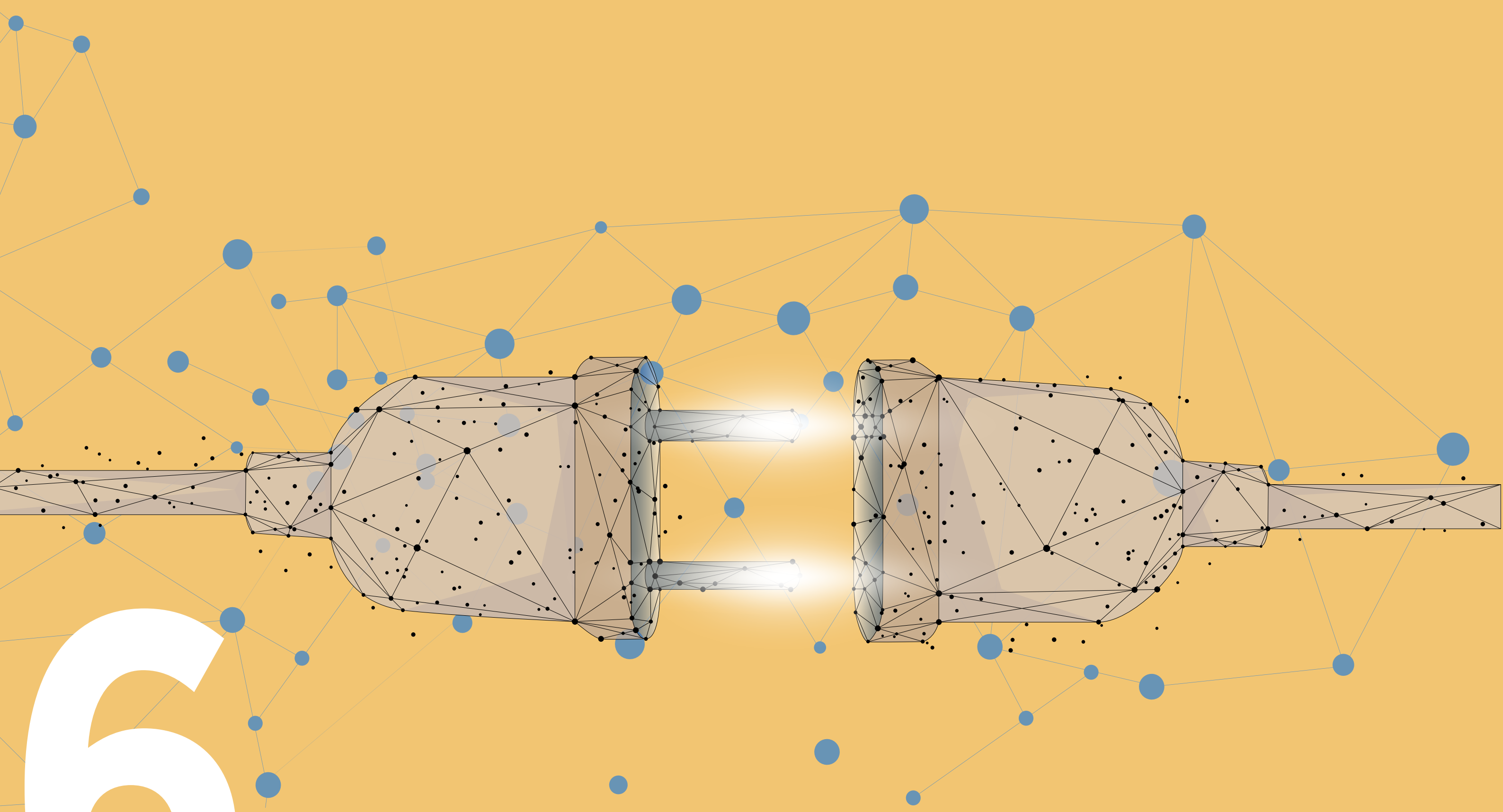
The scope of collaboration through sharing is huge. To develop its full potential, awareness about this component, favourable regulation and a holistic approach to organisational structure design are needed. To give a sense of the magnitude and potential relevance of collaboration through sharing, Table 2 provides an overview of goods and services that are already (or planned to be) shared in the energy sector.

Power system organisational structures can be enablers or barriers for developing the collaboration-through-sharing dimension, enabling or constraining the exchange of energy, space, financing, knowledge and others. An example of this can be found in peer-to-peer electricity exchanges: users, generators and pro-users can exchange electricity directly, allowing users to select specific generators that respond to users' needs or values (renewable-sourced, local, not-for-profit, etc). This scheme facilitates users' empowerment, allowing them to make better use of available energy resources. For this to happen, power system organisational structures must allow peer-to-peer exchanges, as in countries such as Netherlands. But organisational structures in most jurisdictions do not allow direct peer-to-peer trade of electricity, or limits it to retailers and generators, such as in the United Kingdom.

Another example is the use of behind-the-meter thermal storage, back-up storage and electric vehicle batteries to procure ancillary services when they are not used for their main purpose (providing heat, refrigeration, and back-up for critical infrastructure or mobility). Organisational structures are critical enablers for taking advantage of facilities to provide storage when not in use. An example is PJM's experience (District of Columbia, US), where aggregated electric vehicles and stationary batteries are allowed to provide frequency regulation and even to participate in capacity markets (IRENA, 2019c; PJM, 2018).

Organisational structures, in both regulated and liberalised systems, must be designed and operated in such a way that enables the collaboration-through-sharing dimension, unlocking its full potential.

Electric bicycles, Shutterstock



6 A VISION FOR RETHINKING POWER SYSTEM ORGANISATIONAL STRUCTURES: THE DUAL PROCUREMENT MECHANISM

6.1. OVERALL VIEW

Power system organisational structures are designed around social and political goals (see chapter 3) and count on economic and physical allocation and procurement mechanisms to reach those goals, within the system's technical limits. The way in which energy and flexibility services are rewarded brings crucial information in both the short term ("Should we provide this service now?") and long term ("Should we invest in the system and commission a new unit?"). Organisational structures convey the signals that determine the future of the power system.

Increasing indications that current power system structures are unsuited for the energy transition (see chapter 4) have spurred two, contrasting, reactions. On one side, supporters of the traditional fossil fuel-based system have used the misalignments as an argument against renewable energy deployment, focusing on issues such as integration costs or the grid death spiral to reduce support for renewable energy technologies (Agora, 2018; Joskow, 2019; Liebreich, 2017). On the other side, stakeholders seeking to advance the energy transition are engaging in a dialogue around how to make both "system-friendly" renewable energy as well as "renewable energy-friendly" power systems.

Both regulated and liberalised power systems share the challenge of reformulating their procurement and allocation mechanisms to support the post-transition power system and to facilitate the transition process itself.

The discussion on the "renewable energy-friendly power system" can be synthesised in two approaches: gradual correction (or fixes) and systemic change (Table 3). The systemic change approach is based on the recognition that immediate solutions to the so-called energy transition trilemma (how to provide energy that is sustainable, affordable and reliable) are necessary but not sufficient to guide the creation of power system structures fit for the renewable energy era. Indeed, under a short-term vision blind to post-transition energy system requirements, fixes introduced to provide short-term responses can ultimately reinforce structural misalignments and produce transition barriers.

The systemic change approach addresses the requirements of the structures needed by renewable-based energy systems, identifying the root sources of misalignments while taking into account the interactions with the wider socio-economic and Earth systems. Building on improved governance (participation, transparency and accountability), it aims at aligning decision making, institutions, agents and instruments (inside the power system and beyond) with the transition goals and with the wider socio-economic imperatives, setting up organisational structures capable of providing affordable, reliable, renewable energy to all, with the required climate ambition, while helping to reduce inequalities, equitably share benefits and burdens, and build the needed socio-economic resilience to navigate the climate impacts that can no longer be avoided (a fair and just transition).

Tweaks and adjustments introduced to the power system can be useful elements to identify and test solutions in the short term that could then be included in re-designed power systems. For example, the increased time granularity adopted by some European power systems is likely to remain and be part of the power system of the future.

However, limiting progress to the introduction of gradual adjustments without a holistic vision is likely to create transitional barriers as the penetrations of variable and distributed energy resources evolve towards higher shares without the right structures in place.

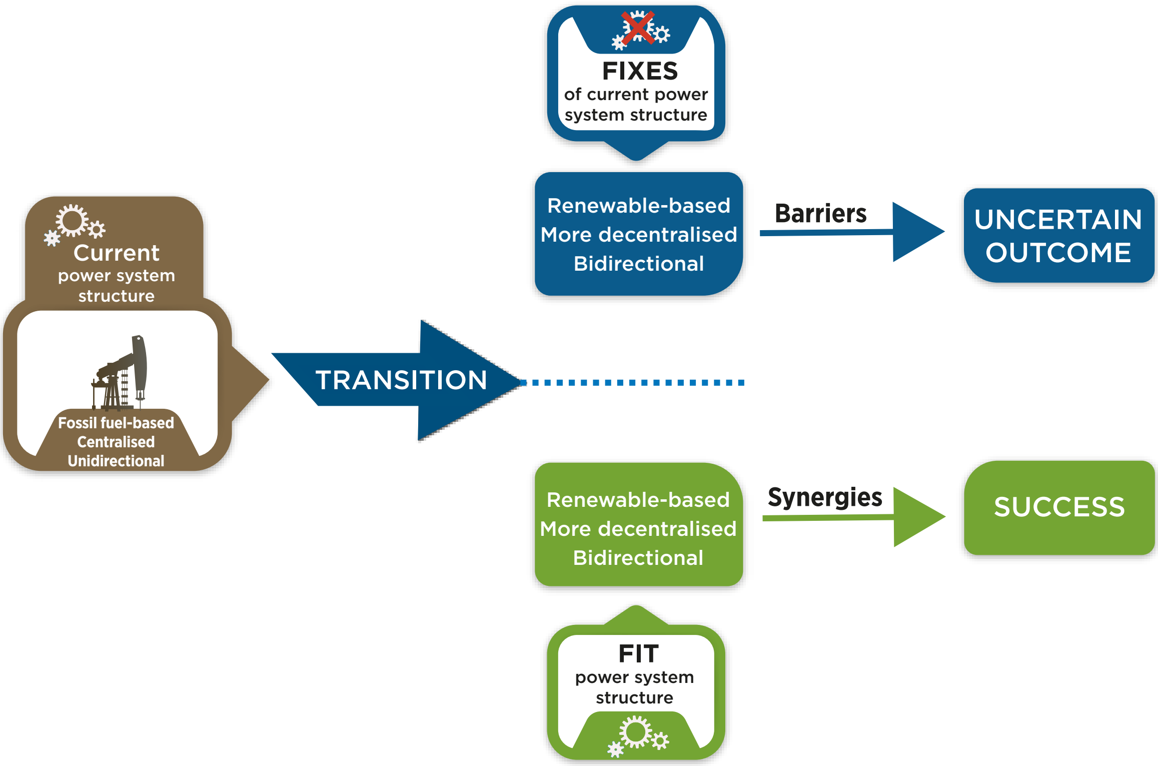
The needed intervention is likely to require a significant re-design of power system structures, so that they properly reward flexibility providers and provide long-term signals to low-OPEX and low opportunity cost renewable generation (IEA, 2011; Joskow, 2019; Keay, Rhys and Robinson, 2014; Liebreich, 2017; Pierpont and Nelson, 2017), while simultaneously phasing out fossil fuels.

TABLE 3. Two approaches to power system evolution

GRADUAL CORRECTION	SYSTEMIC CHANGE
Drivers	
Short-term technical and economic challenges arising in the power system.	Long-term vision on the misalignments arising as the transition progresses, both in the power system and in the wider socio-economic sphere.
Vision	
Provide an immediate solution for an imminent issue of the power sector.	Provide a solution fit for the transition and for the post-transition power system, taking into consideration the interactions between the energy system and the wider socio-economic and Earth systems.
Objective	
Cost compression.	Value enhancement.
Solutions proposed	
Short-term fixes and adjustments of current organisational structures.	Rethinking power system structures to address root causes of misalignments.
Alignment of organisational structures and wider policy and regulatory action	
Limited.	Conducive governance: enabling structures and appropriate policy and regulatory action to make the vision a reality.

Both regulated and liberalised power systems share the challenge of reformulating their procurement and allocation mechanisms to support the post-transition power system and to facilitate the transition process itself (Figure 40). This requires a holistic vision that captures the wider social and system value of electricity, while supporting the deployment of VRE, distributed energy resources, flexibility and system integration, overcoming misalignments and constraints. In pursuing this goal, both regulated and liberalised systems need to find the appropriate balance between regulation, competition and collaboration to shape their procurement and allocation mechanisms. Both liberalised and regulated systems have their own challenges and potentials, and structurally addressing these is a context-dependent process. Improving governance is a cornerstone for the evolution of both regulated and liberalised systems, but how this materialises is system dependent.

FIGURE 40. Impact on the energy transition of how the required power system structure updates are addressed (fixes versus re-design to be fit)



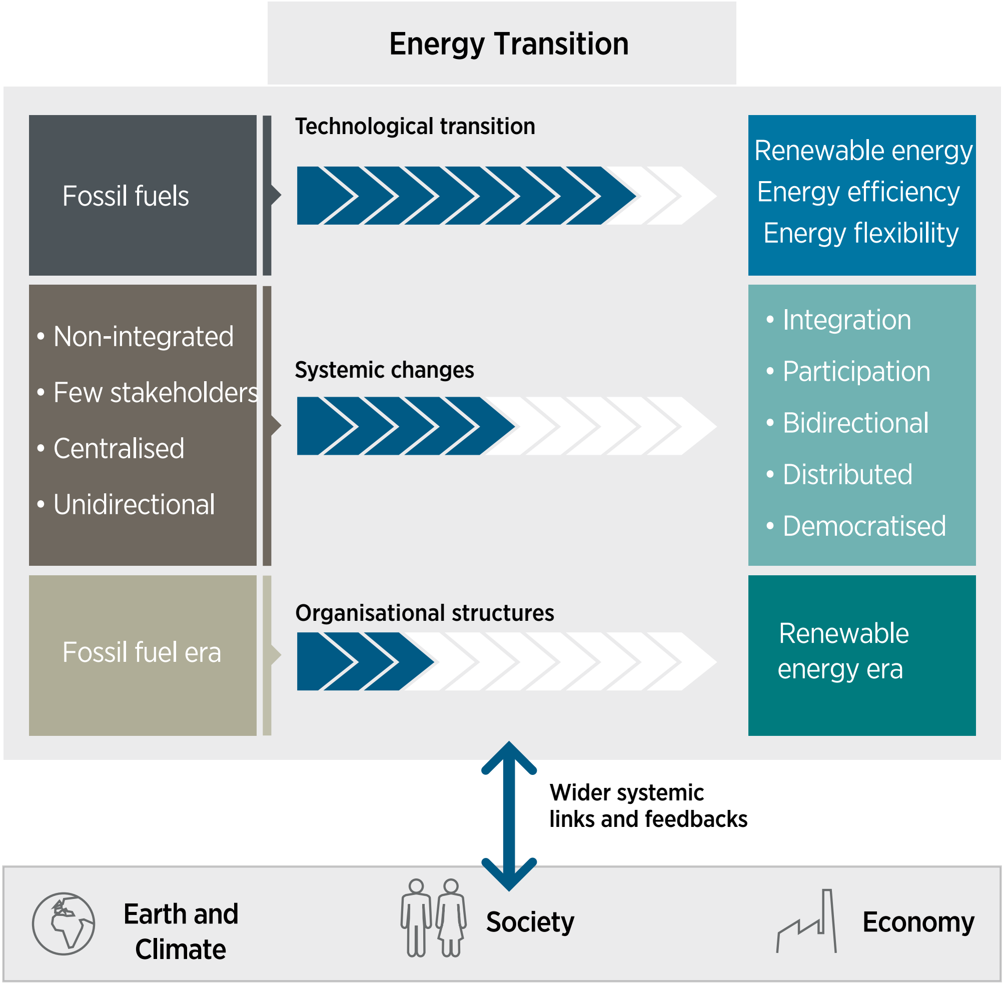
The dual procurement concept presented below addresses the underlying misalignments in power system organisational structures by acknowledging the intrinsic characteristics of renewable energy generation and flexibility supply, as well as how these interact with the socio-economic system. The aim of this chapter is for the dual procurement concept to act as a lighthouse, informing and guiding the structural evolution of both liberalised and regulated power systems towards the organisational structures of the renewable energy era.

6.2. DUAL PROCUREMENT

The energy transition requires simultaneously advancing along different layers. However, progress to date has been unequal across layers (Figure 41), which may introduce barriers to transition.

Although still far from what is needed, progress in the energy technology layer has been the most significant to date, with renewables, efficiency and flexibility gradually occupying the space of fossil fuels. Further advances in the energy technology layer require both systemic changes and the evolution of organisational structures. Systemic changes lag significantly behind the deployment of energy technologies, but even behind that is the evolution of organisational structures, which have received little attention to date. This section addresses the gap in the organisational structures layer by conceptually discussing a power system organisational structure that is appropriate for renewable-based power systems: dual procurement.

FIGURE 41. Unequal advance in the different transition layers



In the renewable energy era, power systems will have two fundamental and differentiated attributes: renewable-based generation (mostly VRE) and flexibility.[70]

Renewable electricity generators and flexible resources have different characteristics. Short-term marginal prices may become unable to guarantee cost recovery to VRE plants as their increasing penetration depresses wholesale prices. Stable long-term payments are far more appropriate for procuring renewable generation, given their CAPEX-intensive nature. Flexible resources have different characteristics and are more likely to be efficiently procured through a short-term marginal pricing mechanism that, unlike the current one, is no longer affected by the price-depressing trend introduced by VRE generation and the pricing caps to prevent windfall profits for non-flexible bulk generation (because VRE procurement would be addressed in parallel).

The dual procurement proposal addresses this dilemma by splitting the procurement of renewable electricity and flexibility into two complementary procurement mechanisms that acknowledge the different characteristics of these services, hence directly addressing some[71] of the misalignments documented in chapter 4.

[70] Flexible resources, such as batteries, demand-side resources, pumped hydropower, dispatchable renewables, increased system visibility and integration, and increased cross-border trade will play the cornerstone role to “fill the gap” between VRE generation and system needs.

[71] Beyond honouring the characteristics of renewable electricity and flexibility services, a holistic vision is needed for dual procurement to address misalignments involving the socio-economic systemic layer.

The two main co-ordinated procurement mechanisms are: are a long-term renewable energy (LT-RE) one and a short-term flexibility (ST-Flex) one.[72] A holistic vision and integrated deployment will be needed for these two procurement mechanisms to properly complement each other.

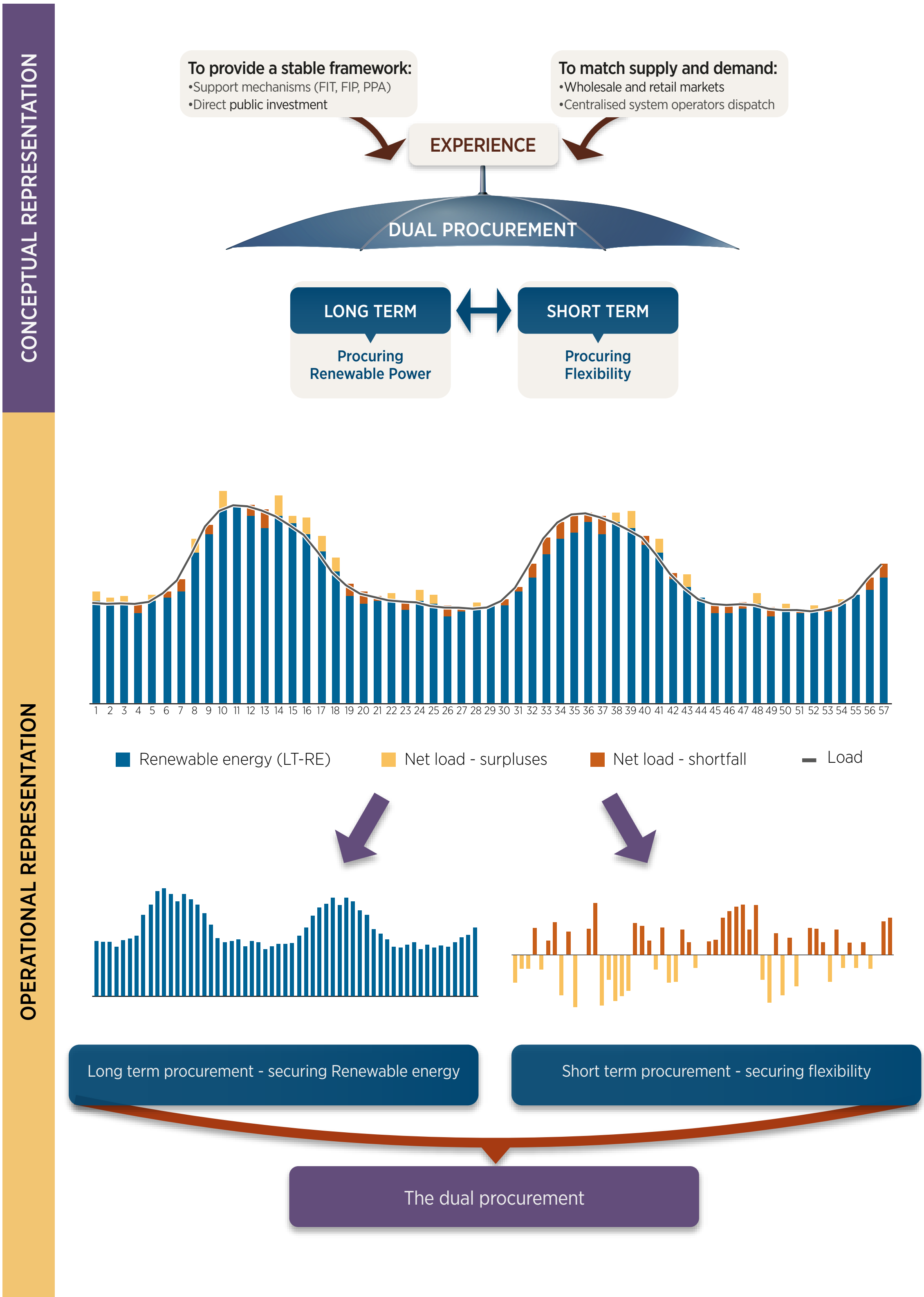
Essential characteristics of the two pillars of dual procurement are described in Table 4. A conceptual and operational representation of dual procurement is provided in Figure 42.

TABLE 4. The pillars of dual procurement: Long-term renewable energy (LT-RE) procurement and short-term flexibility (ST-Flex) procurement

LT-RE procurement	ST-Flex procurement
Based on periodic, long-term, product-based allocation mechanisms (auctions, direct public investment, etc.).	Based on the short-term dimension of current dispatch mechanisms (balancing markets, regulated dispatch, etc.).
Procures renewable electricity (VRE and dispatchable renewable energy) and enables renewable energy supply adequacy with anticipation.	Procures flexibility (demand-side management, distributed energy resources, storage, dispatchable renewable energy, power-to-X, vehicle-to-grid, etc.) and enables flexibility supply adequacy.
Designed to match supply and demand as much as possible in the long term (capturing temporal and locational value to the power system).	Matches supply and demand in the short and very short terms (capturing temporal and locational value to the power system).
Driven by long-term load forecast within integrated energy planning, with appropriate governance and risk sharing mechanisms.	Driven by short- and very-short -term deviations between the scheduled load / renewable energy production and real demand/production.
Provides a safe investment environment that minimises finance costs for CAPEX-intensive technologies.	Liberalised systems: Allows prices to vary from very high to low and even negative, and allows for additional regulated payments if needed (especially during the transition period: LT-Flex). Regulated systems: Provides an enabling framework for deploying and operating the required flexibility capacity.
Designed for the characteristics of renewable energy technologies.	Designed for the characteristics of flexibility resources, including dispatchable renewable power, storage, demand response, vehicle-to-grid and power-to-X.
Recognises the spatial and temporal value of electricity.	Recognises the spatial and temporal value of flexibility.
The economic signals of dual procurement should reach the retail rates (or prices) of all users to promote their participation in system operation, while simultaneously addressing distributional issues so that collaborative engagement is achieved in a just transition.	
Society-wide collaborative governance (public or private), promoting and acknowledging social value creation: Enables effective societal and user participation in planning and operation, fostering the required collaborative framework for social value creation.	

[72] The characteristics of flexibility services may require complementing the ST-Flex with long-term procurement of flexibility (LT-Flex), especially during the transition and for some of the required flexibility services, such as those provided by seasonal storage or system integration. In fact, the share between ST-Flex and LT-Flex during the different stages of the transition is unclear and is likely to be context-dependent. However, the focus here is on the ST-Flex to highlight differential characteristics with LT-RE.

FIGURE 42. The dual procurement proposal

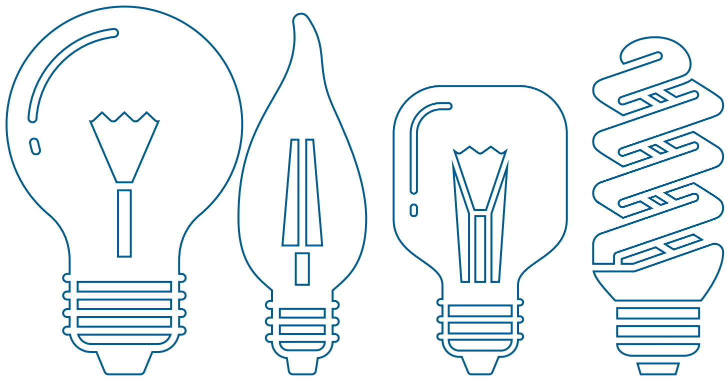


Note: FiT = feed-in tariff; FiP = feed-in premium; PPA = power purchase agreement.

The good news is that the dual procurement organisational structure does not need to be invented from scratch, because most of the tools and experience gained in the past can contribute to dual procurement (Figure 42). It could be argued that this proposal would be the natural evolution of current power systems if a holistic vision and associated policies were in place. Already, in liberalised systems, auctions are becoming one of the more common procedures to procure utility-scale VRE energy, with decreasing prices and increasing design complexity (IRENA, 2019b). Meanwhile, the day-ahead, real-time and ancillary services markets are evolving to the new normal of high VRE penetration, with incremental advances to properly reward and stimulate flexibility. In regulated systems, the long-term procurement of renewable energy generation is also advancing, through IPP auctions or targeted public investment programmes, while flexibility procurement and operation is evolving through integrated energy planning and public investment.

In countries with high shares of VRE and liberalised organisational structures, it is already possible today to perceive the "split" between the procurement mechanisms, with a sizable amount of electricity production coming from long-term energy contracts, in the form of feed-in tariffs, feed-in premiums or bilateral/auctioned PPAs. Indeed, the diffusion of auctions is creating a converging trend between liberalised and regulated organisational systems, with centralised power systems introducing a competitive scheme to procure renewable energy, and liberalised power systems re-introducing elements of state-driven energy policy.

Dual procurement is not even a new proposal. It spurs from ongoing discussions around the phase-out of renewable energy support mechanisms and practical experience with renewable energy deployment. Several previous analyses have contributed to the dual procurement proposal (Barroso and Rudnick, 2021; Forsström, Koreneff and Similä, 2016; Grubb, 2022; Grubb and Drummond, 2018; Joskow, 2019; Keay and Robinson, 2017; Keay, Rhys and Robinson, 2014; Liebreich, 2017; Peng and Poudineh, 2017; Pierpont and Nelson, 2017; Robinson and Keay, 2020; Roques and Finon, 2017).



These analyses and studies still lack a unified and holistic vision, using terms such as "two market" or "hybrid regime" to describe the proposed organisational structure. However, the main concepts discussed are the same: to split the current allocation mechanisms in two, recognising the different technical and economical nature of VRE and flexible resources. Evolving towards organisational structures suited for the renewable energy era requires framing these concepts under a holistic vision and systems approach (Box 26).

In the following sections, guideline principles are presented to provide an initial blueprint for the dual procurement structure of the future.

Box 26. Requirements for evolving from current organisational structures towards dual procurement

- Clearly identify the root causes of current misalignments and constraints.
- Have a clear holistic vision of the post-transition energy and power systems needed to meet the ambition and resilience imperatives, with an adequate policy framework to support and enable the energy transition while addressing the wider interactions with the social, economic and Earth systems.
- Adequate governance to enable policy and regulatory action to make the vision a reality while fostering the required participation and collaboration.
- Acknowledge that what today are additional regulated payments can become one of the pillars of the required organisational structure.
- Maximise synergies between the two pillars of dual procurement as well as synergies with the transmission and distribution grids, while fostering technological and geographical diversification of renewable and flexibility resources.
- Develop participatory frameworks that enable the required collaboration with power system users for demand to have a good alignment with the LT-RE generation profile.
- Promote society-wide collaboration enabling effective participation in design, planning and operation of the power system as well as its systemic interactions with the wider economic, social and environmental systems.
- Maximise socio-economic and environmental benefits: In liberalised systems by aligning competitive drivers with social goals, and in regulated systems by fostering effective public ownership and governance.
- Accelerate the phase-out of polluting technologies while simultaneously providing new generation and flexibility resources at sufficient speed to maintain system reliability.
- Encourage technology and social innovation development, reducing entry barriers to innovative solutions.

Long-term renewable energy procurement

The LT-RE procurement mechanism builds from those experiences that have had the best success so far in deploying renewable energy, such as feed-in tariffs, power purchase agreements and direct investment of VIUs (Box 27).

Box 27. Summary of the long-term renewable energy procurement mechanism

The objective of LT-RE procurement is to cover most of the demand with long-term renewable energy contracts while minimising expenditures and maximising socio-economic benefits.

In LT-RE procurement, a central planner/auctioneer develops time- and geographically characterised demand forecasts and evaluates the needs of generation capacity for system adequacy. Long-term procurement will be driven by this forecasted demand profile and can be articulated (in both liberalised and regulated systems) through competitive auctions, or by direct public investment to develop the required generation infrastructure under a public ownership scheme.

Competition can be introduced in LT-RE procurement through two differentiated ways: competitive procurement of electricity, and competitive procurement of the plant (public investment).

In competitive electricity procurement, the central auctioneer aims to procure long-term electricity to match as well as possible the foreseen electricity demand profile. Selected renewable energy producers (IPPs) are rewarded through long-term PPAs, subject to both plant acceptance and performance requirements. These purchase contracts can be bilateral or centralised.

Under the public investment pathway, the central planner procures through competitive tenders the power plants needed to supply the forecasted long-term electricity demand.

Both liberalised and regulated systems can use these two approaches, or a mixture of them, for LT-RE procurement.

Risk allocation differs between these two approaches. While the procurement of electricity through IPPs allocates the plant performance risk to the IPP, in the public procurement path a significant share of this risk is shifted towards the government (which tries to mitigate it partially through plant acceptance tests).

Another risk is from errors in energy planning, due for instance to deviations in demand or its foreseen geographical and time distribution, or bad forecasts by the central planner. Originally, this error sits with the energy planner, and hence is directly transferred to the shoulders of taxpayers. There are different ways to reduce the burden of this risk on taxpayers, all of them involving improved governance. Periodic revision of energy planning to correct deviations and new inputs is one first step. Good governance in energy planning, with direct and participatory involvement from all stakeholders, is another component.

In LT-RE procurement, renewable electricity is exchanged via long-term contracts, addressing the requirements of capital-intensive technologies facilitating investments at low capital costs, and thereby minimising the cost of renewable power generation while allowing for the appropriate capacity expansion. The dual procurement proposal is not prescriptive of the specific solution to be implemented for LT-RE procurement. The specific instruments and the role that competition, regulation and collaboration play in them can vary widely depending on the socio-political context.

LT-RE procurement can be articulated through different pathways, which can be classified in two broad categories: regulated payments (such as feed-in tariffs or PPAs), and direct public investment and ownership (Box 28). If properly implemented and with good governance in place, these two categories can be roughly equivalent and applicable to both liberalised and regulated systems.

Long-term contracts for power production are used in both liberalised and regulated systems where generation has been opened to private investments through IPPs. Appropriate and transparent competitive auction schemes can help to choose projects that maximise the social and system value.

When LT-RE procurement is articulated through direct public investment, adequate governance needs to be in place to guarantee effective public participation and ownership, with full recognition of the value contributed by different stakeholders and with efficient and sustainable use of public resources. Direct public investment is in turn articulated through competitive bidding for EPC contracts of the whole plant or parts of it, which can even include an operation component. Design specifications and performance guarantees articulated mainly through acceptance tests are key for the efficacy of public investment and the proper allocation of risks.

In this sense, both IPP and EPC procurement by state-owned utilities are equivalent processes from a conceptual standpoint, with the risk allocation marking the main difference between them. In an IPP process the risk of plant performance rests mainly with the IPP contractor, which will be paid through the PPA in proportion to the actual generation achieved by the plant. In an EPC process, the risk of plant performance rests mainly[73] with the public utility. Both approaches include financing risks that will contribute to the overall electricity costs, although publicly owned utilities could access better financing conditions[74] and limit profit-making requirements to those parts of the process not internalised.[75]

The LT-RE element of the dual procurement organisational structure introduces a fundamental conceptual shift with important policy implications. Today, under the established narrative, competitive auction systems providing long-term rewards for renewable generation are often considered a support mechanism (even a subsidy) that should eventually be phased out once renewables become competitive with conventional generation. However, as discussed in chapter 4, this would produce a fundamental misalignment in the organisational structure, to the point of it becoming unable to support a renewable-based power system. The conceptual shift introduced by the dual procurement proposal is making long-term electricity procurement schemes one of its two main pillars, hence acknowledging that they are here to stay.

[73] Appropriate acceptance testing can partly mitigate this risk, but not eliminate it completely.

[74] And even draw from central bank monetary resources.

[75] However, for those parts of the process that are internalised there could be a potential efficiency difference with the alternative of externalising it, especially when there is limited in-house expertise, which could revert the potential benefit from attenuating the profit-making component.

Box 28. LT-RE procurement options go beyond auctions

Options for LT-RE procurement are diverse, and the choice of the right tool is dependent on the socio-political context.

Auctions and feed-in tariffs have received most of the focus as additional regulated payments to enable LT-RE procurement. However, public ownership of generation assets is another option for LT-RE procurement. In recent decades public ownership has received less attention as a policy option for the generation dimension of power system structures, although in the past it was widely used by virtually all power systems. Even today, many power systems still enjoy the benefits of public ownership legacy.

The perception of the role of public participation in power structures will likely change as the transition progresses and as climate impacts intensify. The COVID-19 pandemic and related economic stimulus packages have already changed the current perception of the role of public intervention and investment in addressing intertwined challenges.

Both the regulated payments (auctions) approach and the public investment paths (Figure 43) can be applied to either liberalised or regulated systems. The auctions approach has gained traction as a convergence component between liberalised and regulated systems, seen as added regulation for a liberalised system and as added liberalisation for a state-owned regulated system. Public ownership can also be applied in both regulated and liberalised systems.

When their respective challenges are properly addressed, both the regulated payment and the public ownership pathways lead to similar outcomes and have similar implications for citizens. The LT-RE procurement pillar should hence be articulated through the most appropriate option for each socio-political context.

In the auctions approach, the risk for the construction and performance of renewable energy plants lies with the IPP contractors. The IPP contractor would contract the EPC contractor to build the plant, using private equity and debt as finance (hence taking all construction risk). Users, through time-extended energy payments, would pay the IPP contractor as per the electricity finally produced (plant performance risk lies with the IPP). The IPP contractor is likely to include profits in its business model (as well as the EPC contractor and equity and debt providers), which would ultimately be transferred to users through their energy payments. With proper regulation, these profits should not be speculative but rather should acknowledge the added value (expertise and risk management), and should not necessarily go to corporations but could be socialised (social enterprise and finance).

The public ownership pathway is broadly equivalent to the regulated payments pathway for users/citizens in terms of having a similar requirement for long-term payments, now articulated as taxes and energy payments. However, this pathway adds more freedom in how the economic burden is shared, and hence facilitates addressing distributional issues (although these can also be addressed in the auctions approach by additional policy layers).

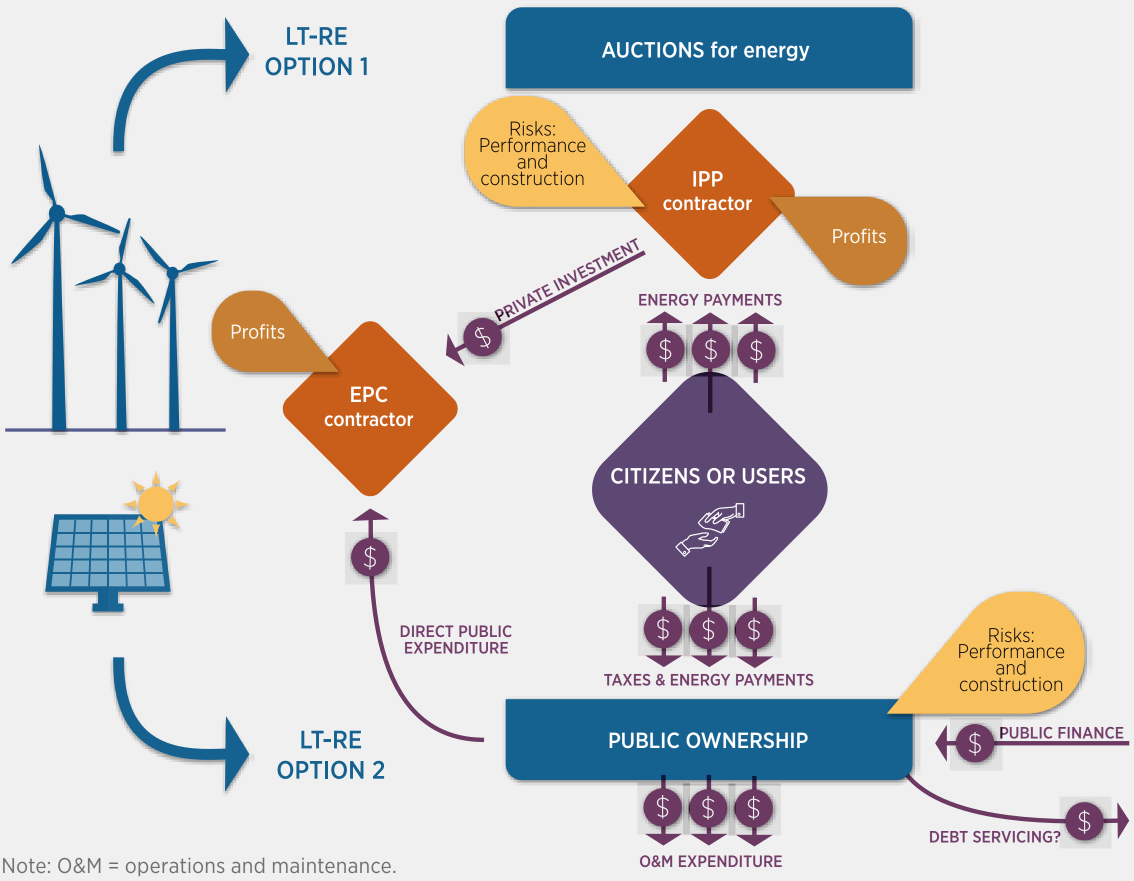
However, in the public ownership pathway monetary flows differ, as well as risk allocation. Construction and performance risks are on the State's shoulders, and hence will have to be managed by it. In the public ownership pathway, the EPC contractor is directly managed by the State through direct public spending. Operational and management expenditure during the plant lifetime also comes from public economic resources. Users are charged through taxes and energy payments to balance the economic resources used by the state, but now without a strict accounting balance requirement within the power sector, since expenses and resources can be balanced at an economy-wide level to better manage the retribution of the provided social value.

Besides risk allocation, an important aspect of the public ownership approach is how the direct public investment is sourced. Direct public expenditure may be financed through a loan by public or private banks. If financed through private banks, the situation is similar to the debt and equity provision to the IPP contractor in the auctions approach pathway, and finance costs will also be similar (depending on the relative state and corporate credit ratings) since they have to produce profit for the private banking sector.

However, other options are available in the public ownership approach, such as public finance by national banks. In the case of public finance, the State has to serve this debt, but it typically can do so with lower interest rates than those from commercial banks. In the case of direct money creation by the State, adequate monetary policies would have to be enacted to control inflation, but there would be no direct debt service (it would be managed holistically within the economy, and hence be able to account for the wider socio-economic benefits associated with this investment) (Kelton, 2020).

Moreover, in the context of the climate crisis and the associated need for an urgent and collaborative response to it, even countries without monetary sovereignty could access international climate finance free of interest and even with null or reduced debt repayment requirements. This could be an important tool to address fairness and justice transition requirements (IRENA and AfDB, 2022).

FIGURE 43. **Energy auctions and public ownership: Two LT-RE procurement pathways**



Note: O&M = operations and maintenance.

Fostering effective participation

Attention should be given to reducing entry barriers for new stakeholders such as households, small and medium-sized businesses, sector coupling, municipalities, co-operatives and energy communities, since this is a pre-condition for triggering the needed collaborative effort. In liberalised environments, effectively involving some of these actors may require articulating out-of-market elements. In regulated environments, this may require implementing adequate participation rules and facilitating infrastructure that empowers decentralised and multi-stakeholder effective and equitable interaction.

The benefits from risk reduction provided by long-term regulated payments go beyond reducing the costs of electricity. Enhanced participation of households, small and medium-sized businesses, communities, energy co-operatives and municipalities, which are usually more reluctant to face risk, is an additional potential benefit.

However, unless properly designed to capture system and social value, competitive auctions based fundamentally on price minimisation displace smaller stakeholders that are not able to play with economies of scale, to get access to cheap financing or to fulfil technical, economic or administrative criteria in the pre-qualification phase (Fell, 2017; Grashof, 2019; IRENA, 2017). This tends to favour large-scale developers and to disadvantage society-led initiatives, negatively impacting local economies and employment and resulting in lack of social participation and acceptance.

In both regulated and liberalised systems, governance should include the right to participate in the design, planning and operation of the system for all users, directly or via aggregators. LT-RE procurement mechanisms can include non-competitive (out-of-market in liberalised systems) mechanisms tailored to promote high social and system value projects and to retain stakeholder diversity thanks to wider public engagement. These can be, among others, feed-in tariffs or feed-in premiums, fixed prices indexed to (but not equal to) the large-scale competitive auctions, and net billing schemes.

Helping to create quality employment

Quality job creation is an essential element of a just transition. LT-RE procurement should take into account existing domestic resources and capabilities, identifying ways to maximise domestic value creation by leveraging and enhancing local industries.

Local content requirements are often adopted to support nascent and domestic renewable energy industries and to maximise local value creation by stimulating demand for locally sourced equipment and services. Increasing the depth, length and diversity of renewable energy supply chains is a crucial factor for maximising the local benefits from the energy transition. This requires a holistic approach to transition policy making, reaching far beyond the energy sector (IRENA, 2020c).

A concentration of projects in resource-rich regions can overload certain regions and disadvantage others. Locational signals embedded in LT-RE procurement can also be used to foster social value creation by targeting the deployment of new capacity in areas where it maximises social value. A more even regional distribution, together with a proper balance of large-scale and distributed resources, can help spread the socio-economic benefits of renewable energy projects and improve the system's resilience.

Short-term flexibility procurement

The LT-RE procurement mechanism cannot deal with the details of the short-term electricity supply to match demand, but only with a coarse approximation to balance generation and demand. It is not possible to perfectly forecast both demand and supply even one day ahead, much less years in advance. Hence, differences will always exist (although smaller if proper LT-RE procurement is in place) between the electricity procured via LT-RE and the final load. This difference would be settled through flexibility procurement mechanisms. Procuring flexibility is mainly driven by short-term requirements and dynamics, since this service deals with aligning demand and generation in the very short term. Moreover, the characteristics of flexibility supply are in most cases well aligned with existing short-term procurement mechanisms, such as marginal pricing wholesale electricity procurement.

Therefore, a short-term flexibility (ST-Flex) procurement mechanism may be expected to play a major role in dual procurement by complementing LT-RE procurement. This is why this report focuses on the ST-Flex component of the flexibility pillar from dual procurement. However, a long-term flexibility (LT-Flex) component could also play an important role in the flexibility pillar, both to smooth the disruptive elements of the transition process (guaranteeing flexibility adequacy throughout) and to address specific characteristics of some flexibility services (such as seasonal storage and system integration). Whether LT-Flex procurement will remain a secondary component from the flexibility pillar, mainly reinforcing the ST-Flex component, or whether it will take on higher relevance, is likely to be context and time dependent.

Battery room, Shutterstock

Box 29. Summary of the short-term flexibility procurement mechanism

The goal of ST-Flex procurement is to meet the difference between generation from LT-RE procurement and real-time electricity demand.

In simple terms, ST-Flex procurement is responsible for the dispatch of the portion of electricity not covered by LT-RE procurement, which can be understood as the remaining "net load", as well as for managing the surplus of LT-RE generation on top of final demand. The ST-Flex procurement occurs through the activation and dispatch of flexibility resources including demand-side response, distributed energy resources, storage, dispatchable renewable energy and sector coupling (*e.g.* vehicle-to-grid, power-to-X).

The ST-Flex procurement mechanism should also provide appropriate investment incentives to meet the power system's flexibility adequacy criteria. For this purpose, and depending on context and time along the transition, ST-Flex procurement may need to be complemented with a LT-Flex component.

The ST-Flex dispatch is based on marginal costs, although additional regulated payments could be in order.

In many ways, the ST-Flex dispatch is similar to current dispatch systems such as those from wholesale markets (day-ahead, intra-day and near-real-time markets), cost-of-service dispatch by VIUs and short-term balancing performed by system operators. The main difference from current dispatch mechanisms is that instead of attempting to dispatch all generation with this single mechanism, ST-Flex procurement deals exclusively with flexibility resources, with the bulk of electricity having been allocated by LT-RE procurement and hence not obtaining windfall profits from flexibility services it does not provide. Other differences are the participation of a larger array of actors beyond energy generators, higher time granularity, and wider spot price ranges to capture the system value of flexibility as a function of location and time.

Design of ST-Flex procurement rules will need to align prices with the value of flexibility for the system and society as a whole, equilibrating the roles of production and demand, favouring shifting business models from product-based to service-based, and guaranteeing the increased effective participation of all agents.

In ST-Flex procurement, the short-term system reliability is guaranteed by a liquid and multi-actor exchange system. It is based on marginal pricing, with a granular bidding format and without scarcity price caps that could limit the economic feasibility of investments in flexibility. It deals with the resulting "net load", the difference between the final load and LT-RE production, by means of the activation of sustainable flexibility assets.

As with LT-RE procurement, ST-Flex procurement can have both more regulated or more liberalised versions, with many of the challenges being common to both. Once the power system gets closer to real time, its operation requirements are alike under both regulated and liberalised organisational structures. Under optimal information conditions (the system operator having full visibility/knowledge of real marginal costs) and under optimal market conditions (no market power, without speculative action, accounting for externalities) both the liberalised and regulated version of this allocation process would lead to the same result.

Thus, as occurs with LT-RE procurement, both liberalised and regulated versions of ST-Flex procurement can be used in accordance with the existing socio-political context, with the common challenge being to have adequate governance to overcome failures through collaborative mechanisms. The most liberalised versions should take measures to avoid market failures such as market power abuse, elements of speculative action or ignoring externalities. More regulated versions should address better access to information on the costs of power and flexibility plants (especially if generation has been opened to plants operated by private firms). In both, it is essential to establish proper governance that allows for effective society-wide collaborative participation.

A space to settle deviations

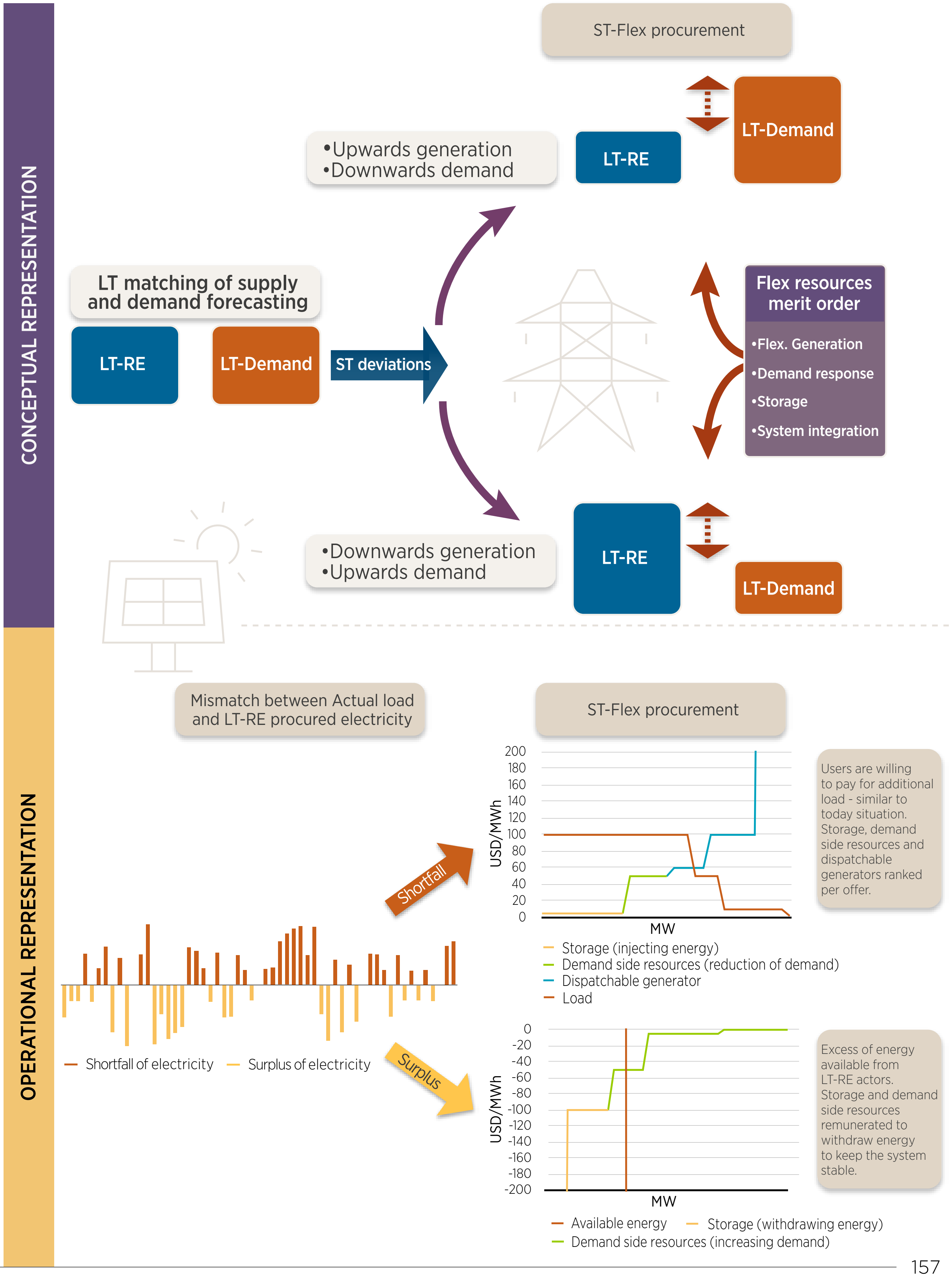
It is not possible to perfectly forecast both demand and supply a day in advance, much less years in advance. Once energy products have been contracted in LT-RE procurement, the electricity system still needs to ensure its reliable operation in real time: electricity must exactly match demand in any moment and location.

The ST-Flex procurement concept is an evolution from the design features of the day-ahead and intraday markets currently in operation, with gate closure closer to dispatch in order to capture the full value of flexibility. However, ST-Flex procurement would differ from the current electricity dispatch structures in both liberalised and regulated systems.

A key difference would be the participating actors. In current operational structures, the supply curve is composed of energy generators, and the demand curve of potential consumers and central procurement bodies. In ST-Flex procurement, these roles would be more nuanced, with a plethora of actors capable of offering both upward and downward regulation.

Deviations from LT-RE procurement can be in both directions, with actual renewable generation lower than actual demand or vice versa. In either case, both generation and demand can help to establish the balance through its participation in ST-Flex procurement. If actual renewable energy generation is lower than actual demand, the ST-Flex mechanism can procure either upward generation or downward demand. If actual renewable energy generation is higher than actual demand, the ST-Flex mechanism can procure either downward generation or upward demand. In ST-Flex procurement, flexibility resources are dispatched by merit order (Figure 44).

FIGURE 44. ST-Flex procurement to address deviations between generation from LT-RE procurement and actual demand



Based on short-term exchange

ST-Flex procurement is based on short-term signals. Hourly exchange is unfit for high shares of VRE. The settlement of energy exchange in both the day-ahead and real-time markets should thus happen for much shorter time frames, ideally around 15 to 5 minutes, affecting both the financial settlements and the dispatch schedule. Five-minute financial settlement is likely to become the norm, as has occurred in Australia (AEMC, 2017; Filatoff, 2020; IRENA, 2019c).

Locational value

ST-Flex procurement should also incorporate elements capturing locational value, differentiating the value of flexibility between locations on the grid, hence contributing to reduced curtailment and grid congestion.[76]

Procurement structures with high geographic resolution provide an accurate economic representation of the physical reality and operation of power systems, and hence facilitate overall system cost minimisation and value maximisation. These have become common in parts of the United States, where markets such as ERCOT (Texas) use locational nodal pricing. The system operator uses as inputs the characteristics of the transmission system and of the resources bidding in the market to solve a large-scale market model for the least-cost system dispatch. The model also generates prices for every node on the grid.

High-resolution design constitutes the benchmark for short-term procurement structures and can reduce the overall costs of operating power systems (IRENA, 2019c; IRENA, IEA and REN21, 2018).

[76] Note synergies with the LT-RE locational procurement signals: with both LT-RE and ST-Flex accounting for locational value, overall system costs can be minimised through collaboration.

Enabling all actors

Short-term markets improve liquidity and competition by enabling more resources to fully participate, especially those resources that are more flexible. Regulated systems also benefit from increased participation. All clean flexible resources – those that can generate rapidly, hold back generation, consume, or store and shift electricity – should be enabled to participate directly in ST-Flex procurement.

The participation of aggregators in ST-Flex procurement should be facilitated. By managing a diversified portfolio of flexibility resources, each of which can provide a range of flexibility services, aggregators would have the incentive to effectively manage flexibility risks and find the right balance between competition and collaboration to maximise value.

No administrative cap to the scarcity price

Most current marginal pricing systems set a limit on the maximum price achievable in wholesale markets. This is done for political reasons and to avoid market power abuse. However, this can be distortive for the adequate price formation when sourcing flexibility. More effective scarcity pricing could encourage ST-Flex procurement participants to react to price signals and to be available when they are most needed, while allowing them to recover investment costs. It is therefore critical to ensure that administrative and implicit price caps are removed to allow for scarcity pricing to play its role in flexibility procurement.

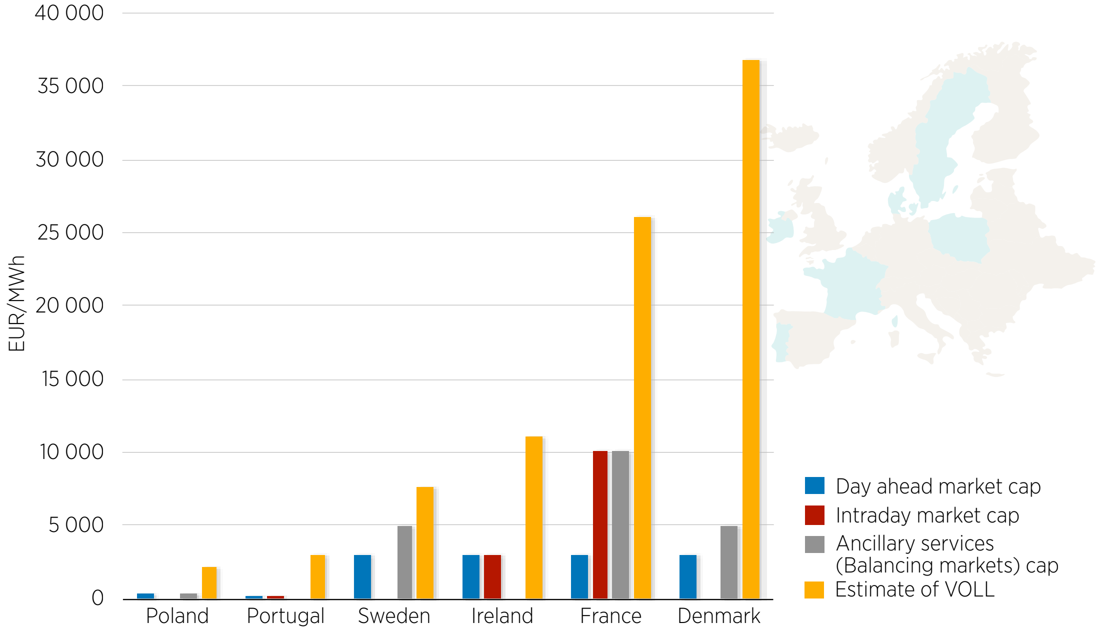
By separating the LT-RE and ST-Flex procurements, one of the main issues with unlimited scarcity pricing is directly addressed. Not all generation in a scarcity event will be rewarded at the scarcity price, only the generation and demand components supplying the required flexibility, which minimises the chance to generate windfall profits, and prevents high overall electricity price volatility and impact on users. Hence, scarcity pricing facilitates flexibility system adequacy without jeopardising the possibility of offering reliable and stable prices to final customers. Moreover, a large number of actors in the system will reduce the occurrences of scarcity events and the level of the associated scarcity prices.

However, as some demand may remain inflexible to prices, if needed energy authorities can still fix the maximum price the ST-Flex procurement can be cleared. An adequately determined value of lost load (VOLL) can be used for this purpose. VOLL represents the price that the overall system is estimated to be willing to pay to avoid outage. The VOLL can be estimated by energy authorities considering various socio-economic factors, as well as time-related considerations (loss of load at 4 a.m. may not have the same impact as the loss of load at 4 p.m.). But the use of VOLL to set a cap on ST-Flex prices at a socially meaningful value requires improved governance and participation to allow all stakeholders, and especially users, to effectively contribute to VOLL determination.

Estimated VOLL values so far explored in liberalised contexts are typically quite high, several thousands of dollars per megawatt-hour above current administrative scarcity caps, as illustrated in Figure 45 for EU markets. Hence, the room to improve flexibility signals is substantial, and in the dual procurement structure its implementation would not have inefficient negative consequences by rewarding all generation at this price: only resources and volumes participating in ST-Flex procurement would receive this price.[77]

[77] Reliability options can also be used to further discriminate how scarcity pricing is distributed across flexibility suppliers.

FIGURE 45. **Difference between administrative price caps and estimated VOLL in selected EU countries**



Source: European Commission, 2016.

A cap on the level of an adequately determined VOLL would provide incentives to invest in flexibility capacity to fulfil the ST-Flex procurement needs.[78] It should be noted that scarcity events are rare in current developed systems, often a consequence of structural overcapacity related to the addition of fossil fuel capacity in the last decades. However, as the necessary phasing-out of fossil fuel plants progresses, clearer price signals will be needed to attract dispatchable renewable energy generation, storage assets and demand-side resources.

Retail rates effectively involving users in system operation (directly or through aggregators) can help to reduce flexibility requirements and hence overall system costs. In the case of dual procurement, users would have the option of either accommodating their consumption to LT-RE procurement (with its time and location distribution), hence accessing low prices by helping to match renewable power generation and demand, or consuming more expensive electricity coming from ST-Flex procurement when they opt to not actively align their demand with LT-RE characteristics.

Policy and regulation would have to complement this approach to guarantee the right of basic energy access to all, shielding the most vulnerable users who are unable to properly engage with price signals, and promoting collaborative approaches to address energy poverty and the inclusion of vulnerable households.

Long-term flexibility procurement component

Even when caps are removed from scarcity events, in specific contexts and especially during the transition, the ST-Flex procurement mechanism in liberalised systems may need to be complemented by a long-term flexibility (LT-Flex) procurement component. This would help guarantee system adequacy in a period when flexibility requirements are increasing. The LT-Flex mechanisms could take the form of capacity auctions targeted to cover a share of flexibility costs, hence complementing the cost recovery mechanism provided by ST-Flex procurement and reducing the risk perception of investors.[79] Direct public investment is also an option for LT-Flex procurement in liberalised systems.

[78] As indicated above, this can be complemented with an LT-Flex component in the flexibility pillar of dual procurement.

[79] Although ST-Flex seems bound to become the dominant component of the flexibility pillar, the final mix of ST-Flex and LT-Flex will be time and context dependent.

Box 30. The end of additional regulated payments and subsidies?

Once VRE has an appropriate procurement mechanism (LT-RE) that is able to properly organise technologies with high capital expenditures and low opportunity costs, then VRE will no longer need additional regulated payments to overcome the unfitness of the current organisational structures. At the same time, ST-Flex procurement, if properly designed and when needed complemented with LT-Flex procurement, should be responsive enough to enable and procure the whole array of flexibility resources, including storage, demand-side response and sector coupling (*e.g.* vehicle-to-grid, power-to-X).

Hence, proper LT-RE and ST-Flex/LT-Flex procurement will eliminate the root cause of most additional regulated payments associated with inappropriate organisational structures, since the appropriate retribution structure becomes fully internalised in the organisational structure.

During the transition, the LT-Flex component could be required to play a similar role as today's additional regulated payments, mitigating risks to enable flexibility providers to undertake, at the required pace, the needed long-term flexibility investments in situations where the utilisation rate and expected prices are still too low or uncertain to guarantee return on investment and reasonable financing costs.

However, since these additional regulated payments would be very focused on specific system needs (in contrast to addressing misalignments), their volume would be much smaller than additional regulated payments under current organisational structures.

Subsidies could still be needed during the transition to accelerate the progression of new technologies along their learning curves, so that the targeted transition rates can be achieved. This could be the case for some of the new flexibility technologies participating in ST-Flex procurement, which are at the beginning of their learning curves. Subsidies targeted at new transition-related technologies and used for this purpose would have similar dynamics to those that allowed the inception of VRE, fossil fuels and nuclear power plants in the past. Loans, fiscal and financial measures to assist the investments, and specific measures to reduce the non-financial barriers (*e.g.* grid codes) may still be needed to trigger the deployment of flexible resources at the required rate.

Another dimension that during the early transition could require measures that are analogous to current additional regulated payments is fostering the effective involvement of users, especially in liberalised systems. Even when supported by subsidies for the acquisition of flexible and controllable devices (heat pumps, electric vehicles, etc.), residential pro-users may still be hesitant to enter into a market (even when pooled with other pro-users through aggregators) when the entry risk is perceived as too high, the returns are uncertain and the market does not really recognise the value of the energy service (SmartEN, 2020).

Fine-tuned (transitional) LT-Flex components could be envisaged to encourage the activation of (especially distributed) resources to face the uncertainty that ST-Flex procurement may pose. Fostering full participation, avoiding distributional barriers (only more affluent users being enabled) and promoting good governance could also require dedicated mechanisms to be factored into LT-Flex procurement.

In regulated systems, the dispatch of flexibility can be techno-economically analogous to that in liberalised systems, *i.e.* based on marginal costing estimates and when necessary backed with an LT-Flex component with similar structure to the LT-RE procurement in these systems.[80] Integrated planning backed with public investment is likely to play a major role in guaranteeing system adequacy by deploying and activating the needed flexibility. Auctions are also an option for LT-Flex procurement in regulated systems.

Ancillary services procurement

Ancillary services (see chapter 3) make up a small portion of total electricity system costs, but nevertheless are a pillar of any power system, providing the means and resources to adapt the last portion of generation and/or load to keep the system reliable, secure and efficient.

System operators currently use various forms of ancillary services procurement mechanisms to ensure the necessary resources for the management and control of the electricity system up to real time, in order to maintain a constant balance between electricity production and consumption and to keep fundamental network parameters stable. In both regulated and liberalised contexts, these procurement mechanisms have limited liquidity and competition due to restriction of participation, regulated prices, and dynamics of procurement. In some power systems ancillary services are not directly remunerated, but rather are part of the obligation of generators to be able to participate in the system.

During the energy transition, meeting the needs of the new power system will require changes to these system services and their procurement mechanisms. Among the more notable changes expected in system services procurement, two have been consistently noted in both research and real-life examples:

- Opening the system service procurement mechanism to a larger number of technologies (demand-side management, batteries, VRE) and from diversified areas (cross-border trade, distribution grids); and.
- The creation of new system service products, to address the new needs created by VRE.

Synergies exist between these two changes, as the new services required may also be provided by the new actors themselves.

New actors for system ancillary services

Today's system service procurement mechanisms are dominated by large centralised power plants based on fossil fuels. Current organisational structures may have embedded limitations to foster participation in providing system services, especially regarding transition-related technologies. Even the current definitions of some conventional system services may not be suited for all the different resources. This limits the resources available to system operators for providing system services (IRENA, 2019c).

The transition increases the diversity and number of actors participating in the power system, while simultaneously requiring non fossil fuel-based service providers. Opening the door to more actors (such as electricity storage, VRE power plants, demand-side management resources and small power plants) reduces the reliance on the current fossil fuel-based service providers, facilitating their phase-out. However, the participation of new actors may require various measures, such as specific grid codes and upgrades to the system services procurement mechanism (IRENA, IEA and REN21, 2018). In conventional power systems, providers of ancillary services are usually connected at the transmission level, but new product providers are also emerging at the distribution level, often co-ordinated by aggregators.

[80] LT-Flex procurement mechanisms such as direct public investment or capacity auctions (to involve IPPs for flexibility).

For example, in Australia specific minigrid operators are already allowed to provide system services (IRENA, 2020c; Villar, Bessa and Matos, 2018).

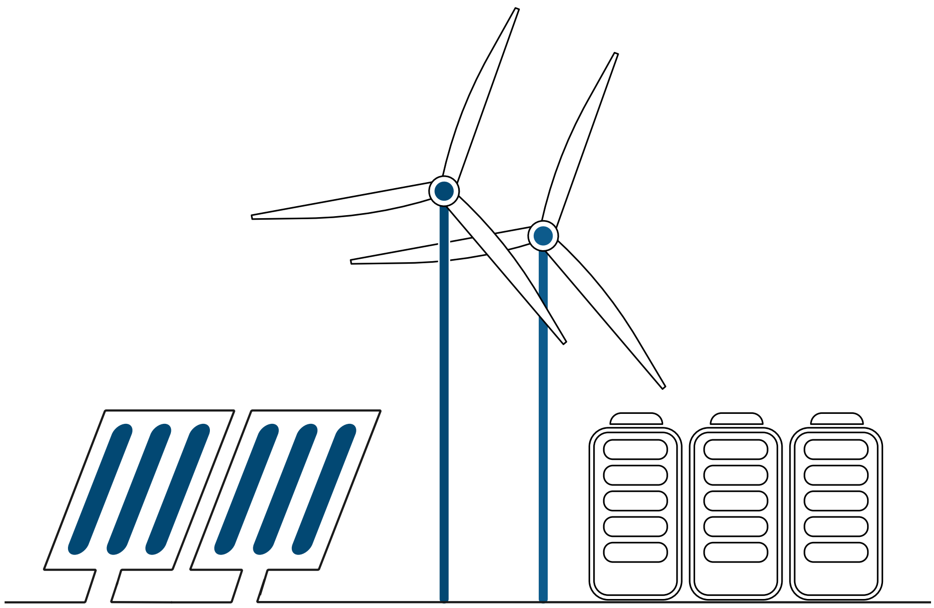
Role of VRE

Within the dual procurement proposal, actors in both the LT-RE and the ST-Flex/LT-Flex procurements may participate in the ancillary system services procurement mechanism, allowing them to stack revenues ameliorating their business case in liberalised systems, and optimising overall costs in regulated systems. With more advanced forecast technologies and control systems, VRE can bear balancing responsibilities, and this is the case in many European markets. VRE producers will have to forecast as correctly as possible their generation and hedge their volatility, hence improving system security and economic efficiency (Joos and Staffel, 2018).

State-of-the-art VRE generators are capable of providing a range of relevant system services to stabilise the grid (IRENA, 2019c), as is already the case in Denmark. In late 2020, for the first time, wind turbines participated in the Danish market for ancillary services providing regulation (*i.e.* ramping up or down upon request of the system operator), helping to supply the services that Energinet, the Danish system operator, needs to maintain balance in the electricity grid. In particular, accurate weather forecasts made it possible for wind turbines to compete with dispatchable power stations, which until recently have been the only options in Denmark to ramp up or down if a fault occurred in the electricity grid, if the weather was windier than forecast, or if consumption was different than expected (Energinet, 2020).

Role of batteries

Batteries are well suited to provide balancing services and fast frequency response because of their short response times (IEA and REN21, 2018; IRENA, 2019c). Indeed, the maximum value from electricity storage is obtained when the operation is co-optimised to provide multiple services, both in the day-ahead and the ancillary services market. The option to let storage provide system services is already in place in different power systems, for example in the United Kingdom (Box 32).



Role of demand-side resources

Power system operators have since the inception of power systems used industrial loads to procure some ancillary services, with interruptible loads being shut down when the grid cannot cope with excessive demand. As control and visibility over both load and system needs are increasing, the active participation of demand-side resources can significantly increase, providing a variety of system services. This can happen for both large industrial loads and aggregated distributed loads. Aggregators, in particular, can provide flexibility at the distribution system level. In liberalised systems this requires having in place a regional/local market for flexibility. Texas, in particular, has a relatively long history of demand-side participation (Box 31).

Box 31. Demand-side participation in the ancillary market

The Texas independent system operator ERCOT has allowed the participation of demand in the ancillary services market since 2002, when the power system opened to competition, encouraging large industrial customers to participate in this market. The demand-side resources participating in the ancillary services market are called "responsive reserve" and provide interruptible loads, by agreeing to curtail their load within 10 minutes of notice. In the beginning, ERCOT allowed only up to 25% of load resources to participate in the responsive reserve market but this share increased to 60% in 2018. By that year, ERCOT had a total of 300 load resources registered, for a total capacity of 4.2 GW (more than the largest single power plant in Texas). The great majority of load resources that provide ancillary services are from the industrial sector and large commercial buildings such as data centres.

New products for system ancillary services

An influx of new technologies in a power system alters its structure, and hence the ancillary services required to cope with the system's needs change. New ancillary services are required that recognise the characteristics of new technologies and the new needs of the power system. Fast reserve, over-generation management and ramping are among the new ancillary services requirements (RGI, 2020).

Fast reserve: This ancillary service could be essential for managing the consequences of a decreasing system inertia, which until now has provided the capability for the system to resist an instantaneous imbalance between generation and consumption through the rotating masses of large power plants. Fast reserve would be a service to deliver a very fast response (activation time below 1 second) by dispatchable power plants and storage. One example is Enhanced Frequency Response (EFR) procurement in the United Kingdom (Box 32).

Over-generation management: This is a service capable of facing the challenge of structural over-generation from VRE (when generation potential exceeds demand). This service could be provided by storage, demand response (industrial processes or aggregated domestic demand) and system integration systems, including electrolysers and vehicle-to-grid.

Ramping: Deviations from expected net load may leave the dispatchable resources with sufficient capacity but without enough ramping capability. In other words, the capacity could be present, but it is not able to meet the set point in time. This challenge is exacerbated if fast dispatchable conventional generators are being phased out and hence the able capacity itself is missing. Ramping service requirements are typically found around sunrise and sunset times in systems with significant solar PV capacity. Ramping services would be provided by system participants that are willing and able to have sharp schedule changes to meet system needs. Examples are the "ramping capacity products" being procured by independent system operator systems in the United States and integrated in their co-optimised dispatch procedures (Box 33).

Box 32. EFR auction in the United Kingdom

The power system in the United Kingdom is losing inertia as thermal generators shut down with the increasing penetration of VRE. Thus, enhancing the ability of the system to respond to sudden power losses or surges has become more important. The UK's National Grid established a new system ancillary services product, called Enhanced Frequency Response (EFR).

Suppliers of EFR have to provide full contracted power output within 1 second. By comparison, the previous fastest frequency response service asked the full output to be ready in 10 seconds. A technology-neutral capacity auction in summer 2016 for four-year contracts rewarded eight battery storage projects totalling 201 MW of capacity at a price range between USD 9.4 and USD 16 per MW per available hour (National Grid, 2019). The successful bids were much lower than average bid prices for conventional frequency response services.

Box 33. Ramping products in CAISO

The California Independent System Operator (CAISO) in 2016 implemented the Flexible Ramp Up and Flexible Ramp Down Uncertainty Awards, which are ancillary services to procure ramp-up and ramp-down capability for 15- and 5-minute time intervals. The product is procured in terms of megawatts of ramping required in a 5-minute duration, and any resource capable of fulfilling the ramping requirement can participate in the procurement process. The price for providing ramp-up and ramp-down services was capped at USD 247/MWh and USD 152/MWh respectively (CAISO, 2018).

Promoting society-wide participation

The role of energy end users is set to change during the energy transition (see chapter 3). This change is already occurring gradually in many parts of the world, becoming an important component of the energy transition that should permeate its organisational structures.

The energy transition will see a larger range of energy services moving to the power sector, directly or indirectly (because of sector coupling). This will imply a larger dependency of end users on the power system and its organisational structures, but also vice versa. The power system and its organisational structures will increasingly depend on distributed resources both for generation and flexibility. This context will trigger greater awareness among users of their potential role in the power system, evolving from the traditional role of passive consumers towards an active role in the design, planning and operation of both the power system and its organisational structures.

Both users and pro-users have an important role to play in the design, planning and operation of both LT-RE and ST-Flex/LT-Flex procurement. Fostering this active role can be instrumental in facilitating and enabling the society-wide participation needed to ensure that the organisational structure is aligned with the goals of climate ambition and resilience building. The participation of users and pro-users in organisational structures could be direct or indirect. Indirect participation may happen by resorting to aggregators, energy communities, minigrids, or via a public body representing users that cannot participate directly, because of technical or complexity barriers.

Billing strategies may help to activate flexibility. In particular, time-of-use or near-to-real time tariffs and rates are expected to have a critical role. They can convey to users an economic signal to adapt their energy use in a system-friendly way. However, improved information flows and governance are needed for these economic signals to be effective. Likewise, measures need to be established to guarantee full access to energy and the protection of vulnerable users.

Direct participation

As in current power systems, large users have multiple possibilities to participate directly in the dual procurement mechanisms. They would be part of the demand-setting exercise, providing their future load estimate, and would be able to directly participate in the ST-Flex/LT-Flex and LT-RE procurements.

While direct participation of smaller stakeholders in the operation and planning of the ST-Flex/LT-Flex and LT-RE procurements might encounter technical or complexity barriers, they could still directly participate in the design of the power system organisational structures and related procurement mechanisms through direct consultation, given appropriate governance.

Aggregated participation

As small users may encounter technical or complexity barriers to their direct participation in planning and operation of the LT-RE and ST-Flex/LT-Flex procurement mechanisms, they could find strength and organisational efficiency in numbers, associating in various forms to reach a certain size and characteristics of load that is more convenient to participate in both procurement mechanisms.

End users could contract with aggregators to manage the participation in procurement mechanism on their behalf, much like today's energy retailers[81] do with the consumption dimension.

Indirect participation through aggregators has important privacy and decision-making implications. A partial transfer of control over flexible resources to aggregators is needed for aggregators to be

[81] In this sense energy retailers could evolve towards the role of aggregator by integrating the emerging roles of users and pro-users in power systems.

able to effectively operate. For this transfer to happen, the specific contractual terms of activation of flexibility resources are key to keep the balance between the agility of the aggregator, the comfort of the asset owner, the transparency and accountability of the aggregators' operation, and the respect of users' privacy.

Participation of flexibility stakeholders, especially smaller ones, in the design of the contractual terms and rules for the aggregator to decide when and how the user's asset would be activated and under which economic conditions, is essential to create the trust relationship needed for participation.

Contractual terms can be negotiated directly by the private aggregators in more liberalised systems (with an appropriate regulatory framework) and through public participation to set the rules of public aggregators in more regulated power systems. For both liberalised and regulated systems, a better balance of the profit and social goals[82] can be reached through proper governance where decision making reflects the wider social interest.

Minigrids

A minigrid can be defined as a limited set of electricity generators interconnected to a distribution network that supplies electricity to a localised group of users. Minigrids may be connected to a distribution or transmission system through a parent connection point or be completely isolated, while being prepared for eventual main grid arrival. Minigrids can provide owners and tenants a convenient way to share the benefits of locally produced distributed energy resources.

If connected to the main grid, the minigrid operator may be enabled to buy energy from an energy retailer and then resell it to end users at the site. They may also be enabled to aggregate distributed generation and grid services from users and make it available to the LT-RE and ST-Flex/LT-Flex procurements, or to manage them internally to reduce energy expenditures. A prominent example of the minigrids model comes from Australia (Box 34).

Box 34. Australia's embedded networks

In Australia, the so-called embedded networks (minigrids recognised and regulated by the system operator) provide value not only to users, who can access clean, inexpensive energy and participate in community-owned distributed energy resource systems, but also to the grid. Today, embedded networks can provide frequency control, voltage regulation and demand response services. With storage, embedded networks can enjoy tariff arbitrage and delayed solar PV self-consumption.

The Australian example shows the potential of a market redesign 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.

[82] Aggregation may be based completely on not-for-profit motives. In these cases, the participation in the pool would not be based on a market agreement, but on a social agreement about the use of energy. Examples could be energy communities, co-operatives or municipal entities.

Protected users

More vulnerable users may not find it possible to actively engage in the organisational structure, by for instance changing their behaviour in energy use, or facing upfront investment in smart appliances, or distributed generation or storage. Their precarious economic situation might make them risk averse towards more complex contractual terms with an aggregator and more vulnerable to volatile electricity prices on the ST-Flex procurement mechanism. Collaborative approaches to support the participation of vulnerable households in dual procurement will be needed.

For these users, the energy authority should find regulatory measures to guarantee them fair electricity prices while adopting measures to foster system-friendly behaviour. In many liberalised retail markets, public retailers with the task of protecting consumers have long existed (for example, the "Acquirente Unico" in Italy), and they could still play a role in the dual procurement proposal.

Public retailers would be entrusted with assuring electricity supply at just prices to protected users. To meet this objective, the public body may sign long-term bilateral PPAs or participate in the dual procurement mechanisms, and implement a tariff structure that captures the social value of electricity access and the elimination of energy poverty, factoring in the required redistributive elements.

6.3. TRANSITIONING TO DUAL PROCUREMENT

Without attempting to develop a detailed roadmap, this section provides some highlights on the transition from current power system organisational structures towards the dual procurement concept.

Firstly, awareness is needed about the requirement to transition the systemic layer of power system organisational structures, with focused policy action, so that these structures can enable and support the transition in other systemic layers. This report aims to help do this by inclusively (covering liberalised, public ownership and hybrid systems) and thoroughly laying down the conceptual framework and outlying a potential way forward: dual procurement.

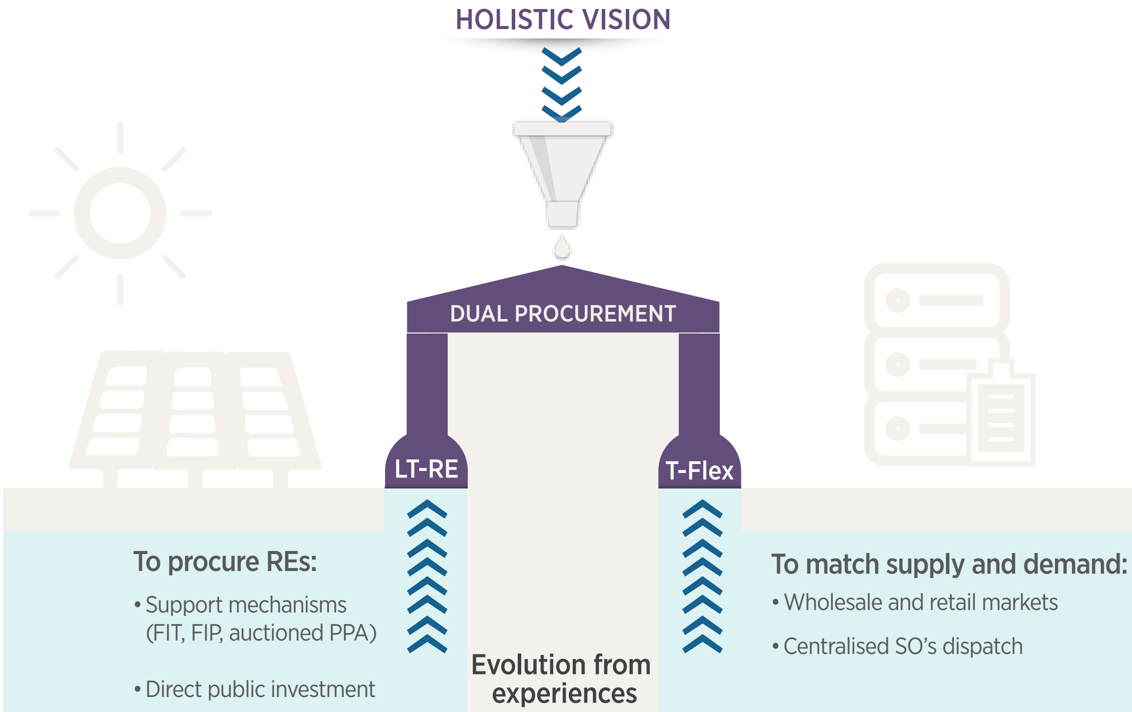
When considering how to implement a roadmap to transition from current power system organisational structures to the dual procurement conceptual framework, two outstanding concepts come to the forefront: the wealth of experiences and knowhow from current organisational structures that if properly applied can produce a smooth transition; the possibility to transition along both liberalised and public ownership pathways, with significant convergence elements between them.

The dual procurement can smoothly evolve from current experience

The transition towards the dual procurement approach can build upon the experience gathered with existing organisational structures. Its constituent pillars (LT-RE and ST-Flex/LT-Flex) seamlessly evolve from current long-term procurement and short-term elements and experiences, taking advantage of best practices. Feed-in tariffs, auctioned PPAs and public direct investment schemes have proved suitable for supporting the deployment of CAPEX-intensive renewable power plants, properly acknowledging their characteristics and progressively incorporating value considerations.

Temporal and spatial granular procurement mechanisms based on marginal costs provide a good basis for flexibility procurement when the peculiarities of the flexibility resources for the renewable energy era are properly acknowledged. A holistic vision and policy framework is the additional component needed to foster and smooth the evolution from current organisational structure elements to the dual procurement pillars (Figure 46).

FIGURE 46. **The two pillars of dual procurement (LT-RE and ST-Flex) as an evolution from current experiences within a holistic framework**



Although the dual approach has not yet appeared in the political and regulatory debate in a systemic way, as proposed in this report, the need for dealing with the peculiarities of short-term and long-term procurement mechanisms is already present in the daily reality of many power systems. This is illustrated, for instance, by hydro-abundant systems in Latin America. These power systems experience a high volatility of market-clearing electricity prices, alternating between long periods of zero and near-zero prices during wet seasons, to periods of high prices during dry seasons. In response, those power systems have chosen decades ago to combine bid-based short-term electricity dispatch with mandatory and voluntary long-term mechanisms to guarantee system adequacy[83] (Barroso and Rudnick, 2021).

From support measure to backbone of the energy transition: LT-RE procurement

Current additional regulated payments (such as feed-in tariffs and auctioned PPAs) and public procurement schemes for renewable energy are the seeds for the backbone of the LT-RE procurement. The continuous evolution of renewable energy auction and public tendering specification designs, and the emerging trend of introducing socio-economic development requirements in them, can directly feed into the LT-RE pillar.

An important concept is that these components (feed-in tariffs, PPAs, public procurement of renewable energy), originally envisioned to support the deployment of renewables in current power systems, are here to stay as one of the pillars of power system organisational structures, contrary to the extended belief that they would gradually vanish as renewables advance along their learning curves and become cost-competitive in life-cycle terms. The clear understanding of this reality is key for articulating a transition policy framework.

[83] The mandatory long-term mechanisms that Chile and Peru introduced are forward energy contracts, while Brazil introduced energy bundled with reliability products, and Colombia choose contracts for a stand-alone reliability product with energy contracts traded in bilateral markets.

From energy-only to flexibility-only dispatch: ST-Flex procurement

To address flexibility requirements of renewable-based power systems, existing marginalist markets and centralised dispatch will have to evolve towards short-term flexibility procurement mechanisms (ST-Flex) adapted to dispatch carbon-neutral flexible resources suitable for the characteristics of a renewable energy-based power system. By this evolution, ST-Flex will become the other pillar of the dual procurement approach. Having these allocation instruments aligned with the characteristics of flexible resources and decoupled from the long-term procurement of electricity allows higher diversity in participating flexibility resources and can effectively and efficiently guide operation and investment decisions in flexibility.

New flexibility resources are substantially different from traditional ones under all economic, technical and even social perspectives (RGI, 2020). ST-Flex procurement must cater for these peculiarities when evolving from current structures. But to a large extent, the fundamentals and experience needed for the ST-Flex pillar are already being created within current organisational structures. Hence, with a holistic vision as an additional component, a smooth evolution could be expected.

The evolution from current structures to the flexibility pillar of dual procurement is likely to bring about a partial migration of resources currently dispatched under ancillary markets or regulated near real-time settlements to ST-Flex procurement. Ancillary services will still be needed under the dual organisational structure. Ancillary services are the last resource "toolbox" for the system operator to be able to manage near-real-time imbalances and guarantee the successful operation of the power system under all circumstances. The ST-Flex pillar of the dual organisational structure creates a dedicated space for flexible resources to efficiently contribute to the operation of the power system, and hence reduces the size of the system operator's needed "toolbox". Proposals for similar dynamics for partial migration from ancillary services to flexibility procurement can be found in RGI (2020).

Conceptually, in the short term this would differentiate two forms of dispatching flexibility: in energy and capacity terms. The ST-Flex procurement would dispatch flexibility in energy terms (similar to how current wholesale markets and centralised dispatch do) until gate closure time (which would be closer to real time than today's organisational structures, to facilitate participation of available flexibility resources). In the remaining ancillary services, flexibility would be dispatched in capacity terms, in the form of an available capacity to be used by the system operator in case of need. Technological and stakeholder diversity would be much higher in ST-Flex procurement, with the system operator likely sticking with those flexibility resources that are easier to manage centrally.

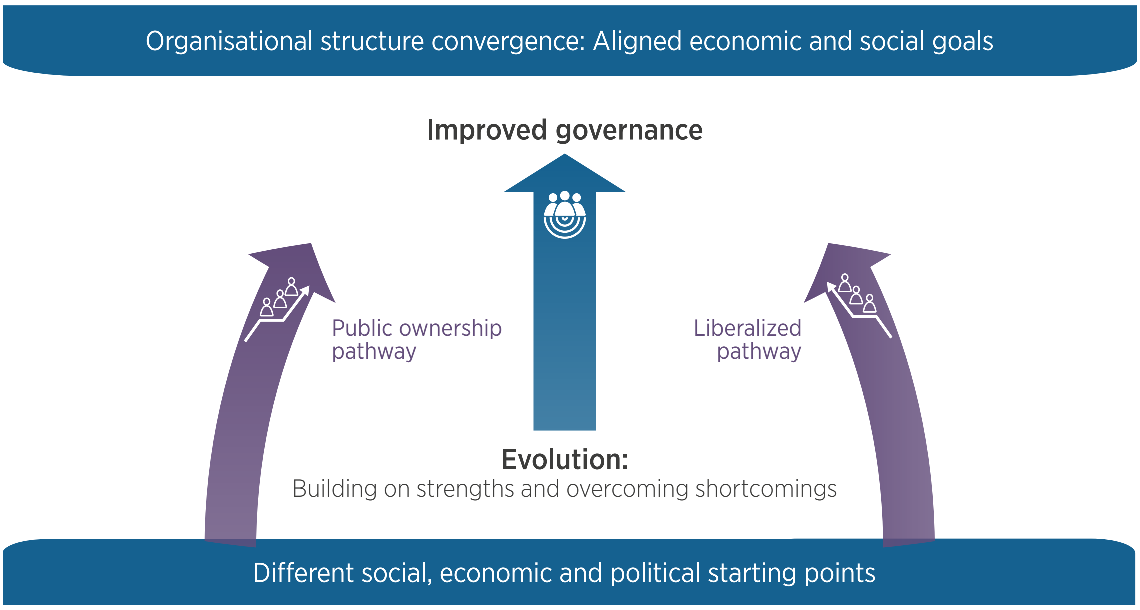
On top of this, as discussed above, there could be a need for an LT-Flex component (in capacity terms) that would complement the ST-Flex component in guaranteeing flexibility adequacy, mainly during the transition period. The accumulated experience with capacity mechanisms could help to shape the LT-Flex component.

Both liberalised and public ownership pathways can deliver dual procurement

In every jurisdiction the transition of the power system organisational structure starts from different social, economic and political standpoints. The appropriate transition pathway for each jurisdiction depends on its socio-economic-political framework. Potential pathways can broadly be classified as liberalised or public ownership. But common trends can already be observed in both: For instance, the proliferation of auctioned PPAs can be interpreted as additional regulation in liberalised systems or as a liberalisation element in centrally planned systems.

The end point of the organisational structure transition is likely to have common elements in both liberalised and public ownership pathways, since they share a final ultimate objective: aligning power system organisational structures with economic and social goals, thereby maximising the value for the power system and society. Moreover, progressing along any of these pathways will require a common compass: improving governance, building on strengths and overcoming shortcomings. The specific balance of collaboration, regulation and competition is path-dependent and will be shaped in an improved governance. In this sense a certain degree of convergence between public ownership and liberalised transition pathways can be expected (Figure 47).

FIGURE 47. **Convergence of organisational structures following the liberalised and public ownership pathways**



This report aimed at providing insights that facilitate undertaking these transition pathways in an inclusive way with regard to the different socio-economic-political frameworks. IRENA will continue to support the transition of power system organisational structures towards those needed for a sustainable renewable-based system that contributes to social value creation.

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