LDES
LONG DURATION
ENERGY STORAGE
COUNCIL

# The journey to net-zero

## An action plan to unlock a secure, net-zero power system

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# Contents

# Acronyms

| | |
|---|---|
| C&F | Cap & Floor |
| CCfD | Carbon Contract for Difference |
| CfD | Contract for Difference |
| CM | Capacity Market |
| COD | Commercial Operation Date |
| COP | Conference of Parties |
| DSO | Distribution System Operator |
| EAC | Energy Attribute Certificates |
| ESS | Energy Storage Systems |
| FiT | Feed-in tariff |
| FOAK | First-Of-A-Kind |
| Gt | Giga tonnes |
| IPCC | Intergovernmental Panel on Climate Change |
| IRP | Integrated Resource Plan |
| LDES | Long Duration Energy Storage |
| LMP | Locational Marginal Pricing |
| MW | Megawatt |
| MWh | Megawatt-hour |
| NPV | Net Present Value |
| PPA | Power Purchase Agreement |
| R&D | Research & Development |
| RAB | Regulated Asset Base |
| RFP | Requests for Proposals |
| ROI | Return on investment |
| T&D | Transmission & Distribution |
| TSO | Transmission System Operator |
| TTF | Title Transfer Facility |
| WACC | Weighted Average Cost of Capital |

# Executive summary

Long Duration Energy Storage (LDES) provides a source of flexible energy that countries will need to achieve fully-decarbonized, secure, reliable, and affordable power grids. While there are limited policy frameworks in place today to catalyse industrialization of the sector, a range of time-tested policies can enable the rapid large-scale manufacturing and deployment of this new energy resource – by acting now, policymakers and regulators can embark on the journey to net-zero.

**Renewable energy will play a critical role in decarbonizing the power grid and increasing energy security, but this large-scale transition will require new sources of flexibility to ensure reliable energy supply.** Globally, the energy transition increasingly has multiple narratives – climate change, energy security, and energy affordability – with the transition away from oil, gas, and coal seen as a significant lever for achieving the above. However, replacing these sources of energy – and the dispatchability they provide – will not be as straightforward as simply adding renewable capacity to the system. The world will need new sources of flexibility that are compatible with a low-carbon society.

**There are a variety of sources of low-carbon flexibility, including demand response, power grid expansion and optimization, and energy storage of various durations.** The precise mix of resources will vary by region, but the path to net-zero power will require combining these sources of flexibility. With greater variability both in terms of how power is consumed by different end-use segments and how power is generated from variable renewable sources, the entire power value chain will need to adapt. Energy storage will be used to improve low-carbon dispatchability of the system at any given time, whether short bursts of energy are required to meet frequency changes or significant quantities of energy need to be shifted in time for optimal use.

**Long Duration Energy Storage will play a key role in delivering net-zero by storing and providing energy in a flexible, low-carbon, and low-cost way.** These technologies can cost-optimally store power for intra- and inter-day durations, ranging anywhere from half a day to a week in capacity, thereby filling a gap between today's batteries and seasonal storage. In the long-term, LDES can contribute insurance against prolonged periods with low or no renewable power output, while in the near-term these assets can potentially act as insurance against elevated power prices such as those electricity consumers are experiencing in many parts of the world today. LDES can therefore contribute directly to the triple imperative of the energy transition, driving greater security, affordability, and lower emissions of power supply.

**Yet today LDES does not have the scale needed for net-zero and faces a multitude of barriers to deployment, with little to no policy support in place to overcome these barriers and drive industrialization of the sector.** The majority of LDES technologies are early-stage with limited commercial scale. Barriers to greater commercialization include uncertainty in the policy landscape, imprecise regulatory definitions as an asset class, high initial project costs, elevated customer and investor perceptions of risk, limited project revenue certainty, and physical infrastructure constraints. Comprehensive policy support is needed to overcome these barriers.

**For the first time, this report assembles a holistic policy solution framework and set of options to catalyse the sector.** This report explores three broad types of support, each with different intended outcomes:

- **Long-term market signals** inform the trajectory of the energy system through planning, targets, pricing of carbon externalities, etc. to offer a long-term vision that LDES customers and project developers can build toward;
- **Revenue mechanisms** enhance the viability of projects by increasing both the absolute revenue as well as the certainty of this revenue; and
- **Direct technology support and enabling measures** create pathways for access and uptake of early-stage technologies

**Policymakers have a wide range of well-tested policies available for consideration.** This report systematically evaluates various policies on their ability to enhance project viability, their relative ease of implementation and their long-term effectiveness in unlocking value for the sector and society:

- In terms of long-term market signals, storage capacity targets, procurement targets, and incorporation of energy storage into grid planning efforts will be key. Carbon pricing and removal of fossil fuel subsidies will level the playing field versus conventional forms of fossil-fired flexibility.
- Revenue mechanisms are most effective in improving project financial viability for customers and investors, including mechanisms that both enhance revenues and provide long-term revenue certainty such as Contracts for Difference, Caps & Floors, Hourly Energy Attribute Certificates, Power Purchase Agreements (PPAs, especially 24/7 clean PPAs), and the Regulated Asset Base.
- Direct technology support and enabling measures can also unlock growth, in the form of public-private partnerships, grants and incentives, and targeted tenders to accelerate early projects and their required infrastructure. Further, narrow definitions of storage in RFPs, standards, and rules will need to be expanded and be more flexible to include LDES.

**A successful approach for building a local market for LDES likely deploys a combination of policies to drive appropriate near- and long-term adoption.** The level of support and applicable types of policies will naturally evolve as the LDES sector matures, as has been the case for policies that supported other clean energy technologies (e.g., German rooftop photovoltaic feed-in-tariff prices have declined as have strike prices in UK offshore wind Contract for Difference auctions). As the power system decarbonizes and LDES become more prominent, entirely new market structures might also be developed, and existing market operation frameworks potentially become less relevant (e.g., marginal electricity prices set by highest cost plants). It is important to note, however, that these mechanisms are no substitute for well-developed pricing signals in balancing, intraday, and day-ahead markets to facilitate effective participation from storage assets. As new technologies emerge and evolve, regular review and revision of rules and standards are important to remove blockers and maintain a level-playing field. Revenue mechanisms may be phased out or scale down over time, as technology costs decline and risk appetite improves.

**The societal savings from large-scale LDES deployment can outweigh the costs of implementing policies.** LDES improves overall utilization of existing renewable generation resources (curtailed energy can be stored and then exported later) as well as of the power grids that carry energy to load centres. This increase in utilization reduces the investment required in standby peaking power capacity or additional power grid expansion. If support policies are designed appropriately, these societal savings can outweigh the program costs, even before accounting for the wider socio-economic benefits of lower carbon emissions or job creation and economic growth resulting from the commercialization of these solutions.

**The journey to net-zero – and the role of LDES in this transition – have many different trajectories that depend on local power market structure, resource mix, and energy transition ambitions.** The urgency of policy action will depend on factors such as existing abundance of flexibility resources (e.g., hydropower resources, significant interconnection capacity with neighbouring power grids, etc.), level of renewable penetration, and energy transition ambition. Each local LDES journey likely begins with the formation of a baseline understanding of flexibility needs over time to reliably meet system goals, followed by steps to understand the local landscape of available technology and requirements of energy system stakeholders. Once implemented, policies and regulations must be regularly reviewed to ensure they remain effective as the market develops and the technologies mature.

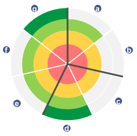
**Policies take significant time to implement – and capital-intensive industries can be slow to scale – so the time to act is now.** Policymakers and regulators can make a difference: by acting today they can help bring about a fall in technology costs and contribute to accelerating the energy transition tomorrow.

# Summary of policy assessment across qualitative criteria

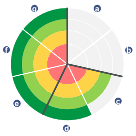
🟩 Very strong 🟩 Fairly strong 🟨 Mixed 🟥 Weak

## Long-term market signals

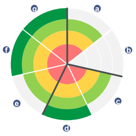
**Carbon pricing**



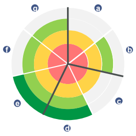
**Grid planning**



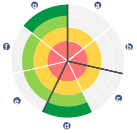
**Phase-out of fossil fuel subsidies**



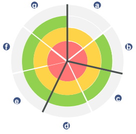
**Procurement targets**



**Renewable energy targets**

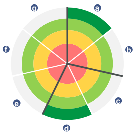


**Storage capacity targets**

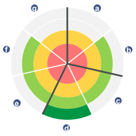


## Revenue mechanisms

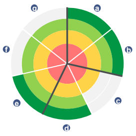
**Cap and Floor**



**Capacity market**

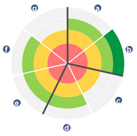


**Contract for difference**

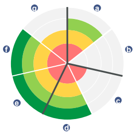


**Hourly energy attribute certificates**

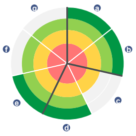
**Long-term balancing services**



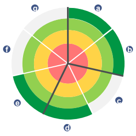
**Nodal or locational marginal pricing**



**Regulated asset base**

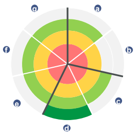


**24/7 Clean PPA**



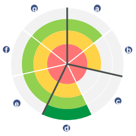
## Direct technology support & enabling measures

**Grants and incentives**

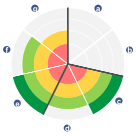


**Investment de-risk mechanisms**

**Market rules**



**Sandboxes**



**Targeted tenders**

**Technology standards**

# 1. Introduction

# Preface

**The LDES Council is a global, executive-led organization that strives to accelerate decarbonization of the energy system at lowest cost to society by driving innovation and deployment of long duration energy storage (LDES).** Launched at the Conference of Parties (COP) 26, the LDES Council (snapshot of current members in Exhibit 1) provides fact-based guidance to governments and industry, drawing from the experience of its members, which include leading technology providers, industry and services customers, capital providers, equipment manufacturers, and low-carbon energy system integrators and developers.

**LDES is defined as any technology that can be deployed competitively to store energy for prolonged periods and scaled up economically to sustain energy provision[1], for multiple hours, days, or even weeks, and that has the potential to contribute significantly to the decarbonization of the economy.**

**In this report, the Council focuses on potential regulatory and policy options to overcome barriers to widespread LDES deployment.**

Such measures will be a critical component of an action plan to deliver the energy transition and to ensure a sustainable and secure energy future for all.

This report is an LDES Council publication. Representatives from individual member companies have contributed to the ideation and drafting of the messages and analysis in this report, but these entities do not necessarily endorse each individual recommendation. Its members have been involved in the drafting of the report but they do not necessarily endorse each recommendation of the report.

**This report is one of many activities the LDES Council membership is pursuing:**

- In May, the Council published a detailed analysis on 24/7 clean Power Purchase Agreements, one of the policies that is assessed in this report. This publication is also available at ldescouncil.com.
- The Council also has active working groups focused on decarbonization of heat and development of platforms for accelerating the sector. A summary of the Council's full research agenda, as prioritized and shaped by membership, can be found online.

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[1] The focus of this report is on LDES solutions that deliver power, but a major focus of the Council 2022 is on expanding the aperture to also consider delivery of heat (e.g., for industrial applications).

Exhibit 1: LDES Council membership

## To date, 50 leading companies have joined the LDES Council to accelerate decarbonization

**Technology providers**

Ambri
AZELIC
Breeze
BRENMILLER ENERGY
cellcube
ceres
ECHOGEN power systems
ENERGYDOME
EnergyNest
ENERGY VAULT
ENERVENUE
ENLIGHTEN
eos
ESS INC
e-zinc
Form energy
HEATRIX
Highview Power
HYDROSTOR
INVINITY ENERGY SYSTEMS
KRAFT BLOCK
KYOTO
MAGALDI
MALTA
MGA THERMAL
PUMPED HYDRO STORAGE
Quidnet Energy
redflow
RheEnergise
Rye Development
SaltX Technology
Stiesdal
STORWORKS
TORC
VOLTSTORAGE

**Anchors**

**Industry and services customers**

COMPASS
EGA
Google
Microsoft
RioTinto

**Capital providers**

Breakthrough Energy
quinbrook infrastructure PARTNERS

**Equipment manufacturers**

Baker Hughes
ALFA LAVAL
INNIO
Sumitomo SHI FW
VOITH
SIEMENS energy

**Low-carbon energy system integrators & developers**

bp
corre energy
greenko
NEOM
Ørsted
Reliance Industries Limited
TotalEnergies

# Motivation and context

## New sources of low-carbon flexibility will need to be deployed in order to de-risk the energy transition. LDES will play a key role.

**The power sector is a key enabler of large-scale societal decarbonization given the ability to generate electricity competitively from renewable sources and to electrify end-use consumption of energy.** The power sector currently accounts for roughly 30% of global carbon dioxide equivalent emissions. Given the sector's increasing role in final energy consumption due to mobility and heating electrification, it is amongst the sectors that will need to decarbonize deepest and fastest to enable lower carbon emissions in other sectors. This transition has significant implications for the power sector and its resource mix and by extension the reliable operation of the wider system that powers modern society.

**The imperative for power system decarbonization is increasingly about enhancing and accelerating energy security.** A system that relies on greater utilization of local and regional renewable resources reduces its dependence on fossil fuels, purchase of which often carries geopolitical implications. Europe has recently reassessed its energy strategy and increased  the urgency of reducing dependence on imported fossil fuels and of finding new, environmentally- and politically-sustainable and reliable sources of this energy supply.[2]

**Flexibility – the ability of a system to respond to changing conditions – and reliability in modern energy systems have typically come from dispatchable fossil-fired resources.** By burning more or less fuel, fossil-fired and particularly gas plants can provide dispatchable energy output with relative ease to accommodate changes in demand or generating patterns.[3] These dispatchable resources have also provided considerable grid services, such as stability in the form of voltage support, inertia, and short circuit level current that enhance the ability of a power system to handle disturbances and maintain normal (and safe) electrical operating parameters.[4] Going forward, the energy system will need new sources of flexibility – which LDES can provide – to address the decarbonization and energy security imperative alongside the continued phasing out of fossil fuel resources.

**These flexibility needs are expected to become increasingly pronounced as renewable energy starts to dominate system capacity and determine system operation.** Solutions like LDES will play a key role in bridging the emergent and growing gaps between periods of renewable energy surplus and deficit to ensure continued reliable system operation.

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[2] The European Commission estimates that in 2021 the EU imported more than 40% of its total gas consumption, 27% of oil imports, and 46% of coal imports from Russia. These figures are averages, with some EU countries more exposed than others.

[3] With associated carbon emissions – a typical combined cycle gas turbine emits ~500kg/MWh of carbon dioxide while peaking plants with higher heat rates are less efficient and therefore more carbon-intensive.

[4] A typical gas plant may provide e.g., ~5 GVAs of inertia or ~3% of the UK's total system-wide inertial requirement (~140 GVAs).

**The concept of low or net-zero flexibility and reliability is not new.** Various technological options exist to improve flexibility of the power system beyond the use of dispatchable generators. Augmentation of power grids to improve meshing (i.e., to create multiple paths for power flow) and interconnectivity between different regions provides significant system flexibility by connecting decentralized supply and demand. Demand side management or response is also an established technique that can control when and how much electricity is consumed by industrial or commercial operations, as are forms of self-generation and consumption via onsite photovoltaic and distributed storage, especially when aggregated and dispatched to optimize for local distribution systems. And lastly, stationary energy storage systems (ESS) offer flexibility, especially for temporal shifting of electricity that will be required as the penetration of renewables increases.

**The roles of these sources of flexibility will become more pronounced with the accelerating energy transition.** Power modeling has indicated a growing need for ESS capacity, both in terms of power and duration, with duration being a particularly important dimension as the share of renewable penetration in generating capacity increases. The U.S. Department of Energy ARPA-E research has shown that the need for such LDES increases significantly when renewables reach 60-70% of power capacity.[5] In the LDES Council's inaugural 2021 market analysis[6], the global need for LDES by 2040 was estimated at 1.5-2.5 TW of power capacity and 85-140 TWh of energy capacity.

**However, building the required manufacturing capacity and establishing supply chains will not happen overnight.** Creating "giga-scale" production facilities takes years for technology companies. Prospecting and developing new mineral resources and supply chains to full output takes years, as does creating "giga-scale" manufacturing facilities. Permitting, building, and interconnecting high voltage power assets may also take on the order of several years. Indeed, to achieve net-zero power by the early 2030s, the industry needs to drive toward commercial scale today. Not deploying LDES means that flexibility is provided by high-carbon and high-cost gas plants or that the reliability of the grid weakens as the sector decarbonizes. Policies and regulations have a key role in enhancing the right signals to start creating the journey, establishing long-term trajectories and regulatory certainty, enhance project viability and create pathways for market access and entry.

**ARPA-E research has shown that the need for such Long Duration Energy Storage (LDES) increases significantly when renewables reach 60-70% of power capacity.**

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[5] This fraction may be lower or higher depending on several factors such as the power generation mix, the growth in power demand, the degree of network meshing and interconnection, etc.

[6] Net-zero power: Long duration energy storage for a renewable grid available online at https://www.ldescouncil.com/insights

# Role and value of this report

This report is directed at policy and regulatory stakeholders navigating the energy transition and its implications. It presents an overview of the potential tools available to them to support commercialization of the LDES sector.

More specifically this report:

- **Recaps the role of LDES as a flexibility solution** and enabler of energy system decarbonization, reliability and security, by de-risking the inherent variability of renewable power sources
- **Highlights key barriers to widespread LDES adoption** that are particularly relevant during the industry's nascency, and that policy can be designed to mitigate or overcome
- **Offers a set of key considerations in developing policy and regulatory frameworks** to increase the likelihood of advancing the commercial maturity and scale of the LDES industry and achieving energy transition goals at reasonable cost
- **Presents and defines different types of actions (and example mechanisms within each type)** with the intent of providing a comprehensive but not exhaustive review of the policy landscape, while also offering examples of how these policy tools are being deployed in selected geographies to grow markets for new clean energy technologies
- **Proposes an assessment framework to evaluate potential options** that can address the key barriers to creating viable markets for LDES resources
- **Uses illustrative business case examples** to showcase the directional impact of applying different policy tools that directly impact LDES project economics
- **Suggests a set of key regulatory and electricity market archetypes** that can be used by policymakers to identify which policy tools for advancing the market for LDES technologies may be most relevant for their jurisdiction
- **Shares key steps policymakers could take to advance the scale of the LDES industry** that are broadly applicable across regions and jurisdictions

Note that many of the policy tool options presented are predominantly applicable to the power sector and the dispatch of electricity. As the LDES Council expands its focus in 2022, to include flexibility solutions for and applications in low-carbon heat, the scope of regulatory considerations may expand to also include delivery of heat as an energy carrier.

# Overview of LDES solutions

**The LDES asset class encompasses a range of technologies that store energy in various forms for prolonged periods at a competitive cost and at scale.** These technologies include thermal, electrochemical, mechanical, and chemical forms, as summarized in Exhibit 2. LDES includes mature technologies like pumped storage hydropower, technologies in early deployment like hydrogen and technologies in R&D like metal anode batteries. These technologies can then discharge electrical energy when needed—over hours, days, or even weeks—to fulfill long-duration system flexibility needs beyond shorter duration (less than or equal to eight hours) solutions, which already have market access in some jurisdictions.[7] LDES are characterized by low marginal costs for storing electricity; they enable decoupling of the quantity of electricity stored and the speed with which it is taken in or released; they are widely deployable and scalable; and they have relatively low lead times compared to upgrading of transmission and distribution grids. At the same time, many of these solutions have high initial capital costs today due to limited commercial scale.

**LDES technologies can play a central role in balancing the power system and making it more reliable and efficient.** Modeling by the LDES Council in 2021 showed that the largest proportion of LDES deployment is expected to be related to the central tasks of energy shifting, capacity provision, and transmission and distribution network optimization in bulk power systems. Further value propositions include support for resource adequacy and firming power purchase agreements (PPAs) to enable 24x7 renewable power. At the same time, LDES can play a role in firming and optimizing energy use for both industrial clients and communities in areas with poor grid access that rely heavily on fossil fuels.

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[7] Lithium-ion is the dominant battery technology applied in grid-scale battery ESS (systems) today, but this class of solutions traditionally also includes nickel or lead-based batteries. The dominant durations for lithium-ion BESS are 1-2 hours of storage, but this figure is increasing to between 4-8 hours in some markets (e.g., California). While in most markets these systems are typically deployed to provide high-value ancillary services such as fast frequency response, these assets are increasingly also participating in in bulk power storage or energy shifting applications, such as in California where many recently-commissioned grid-scale batteries are providing resource adequacy (capacity).

Exhibit 2

## There are four different kinds of novel LDES

| | Thermal | Electrochemical | Mechanical | Chemical |
|---|---|---|---|---|
| Description | Thermal energy storage systems use thermal energy to store and release electricity and heat<br>*For example*: heating a solid or liquid medium and then using this heat to power generators at a later date | Electrochemical LDES refers to batteries of different chemistries that store energy<br>*For example*: air-metal batteries or electrochemical flow batteries | Mechanical LDES store potential or kinetic energy in systems, so that they can release it in the future<br>*For example*: raising a weight with surplus energy and then dropping it when energy is needed | Chemical energy storage systems store electricity through the creation of chemical bonds<br>*For example*: using power to create syngases, which can subsequently be used to generate power |
| Example technologies | Sensible heat<br>Latent heat<br>Thermochemical heat | Aqueous flow batteries<br>Metal anode batteries<br>Hybrid flow batteries<br>Hybrid cathode batteries | Novel PSH<br>Gravity-based<br>CAES<br>LAES<br>Liquid $CO_2$ | Power-to-syngas to power<br>Power-to-hydrogen to power |

# Barriers to LDES adoption

## While there is considerable evidence to support the need for LDES solutions as a part of the decarbonization equation, there are several barriers to widespread deployment of LDES.

1. **Limited policy certainty for LDES, compounded by concurrent jurisdiction**

   While many regions note the strategic importance of energy storage overall, there are few concrete actions being taken to accelerate the sector, let alone LDES within this broader envelope. Moreover, in regions like the EU and US, concurrent jurisdiction between different levels of government (e.g., state vs. Federal in the US, country vs. EU-level in Europe, and state vs. central in India) can create additional uncertainty and complexity to manage.

2. **Limited awareness and definitions of the asset class, leading to narrow technical taxonomy for energy storage and lack of a defined market and monetization opportunities**

   As an emergent class of technologies, understanding of LDES solutions, their attributes, and their value propositions to customers and the power system is also underdeveloped. The term energy storage tends to be more narrowly defined to short duration (commonly one to four hours of storage) and conjures the traditional image of a containerized lithium-ion or lead acid battery pack. Given the high market share of lithium-ion systems in today's grid-scale stationary storage, most of the technical requirements in power markets (e.g., roundtrip efficiency, safe operating parameters, degradation, lifetime, cyclability) are defined based on the performance characteristics of these solutions and will need to be adapted for LDES technologies that can deliver similar services but with inherently different technical and operating profiles. Similarly, in many markets no distinction is made between conventional pumped hydro and novel forms, such as off-stream. This narrow definition of energy storage also extends to customer technology procurement, where existing Requests for Proposals (RFPs) for energy storage projects preclude novel solutions with different characteristics. In some jurisdictions, LDES is also considered as the same asset class as electricity generation or transport, which can lead to double taxation.

3. **High initial project costs[8] due to limited commercial scale and deployment history**

   Limited commercial deployment of LDES solutions beyond first-of-a-kind (FOAK) projects has resulted in high initial capex requirements due to limited economics of scale in production and procurement (refer to Exhibit 3 for high level summary of LDES deployment status). Elevated initial project costs in turn mean lower economic competitiveness versus other established forms of flexibility that have achieved economies of scale.

4. **Investor perception of increased project risks leading to elevated rate of return requirements**

   Project investors require a premium to cover perceptions of higher risk associated with an asset class with limited track record in the early days of market formation. Although there are applications (e.g., substitution of diesel power in remote applications such as mining, or isolated communities including islands) offering sufficient Return on Investment (ROI) today, the majority of LDES business cases cannot support elevated capital cost requirements reflecting technology risk. Additionally, some development banks find it difficult to support LDES because few risk assessments are available.

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[8] Costs of LDES systems are expected to decline significantly to 2040. Benchmarking by the LDES Council in 2021 suggested 60% and 25-50% declines in power and balance of plant capex and energy capex from 2025 levels. Learning rates for LDES assets were estimated to be between 12-18%, comparable to those for other clean energy technologies.

### 5. Existing revenue streams in most markets do not sufficiently compensate LDES assets with necessary certainty for the range of grid services offered

LDES assets can deliver a wide range of grid services including energy, reliability (capacity), and ancillary services (as well as stability products). In most markets, only a subset of these services is compensated, and most often only via short tenor contracts or without any multi-year offtake agreements, such as in wholesale energy markets (which can have significant variability of returns). There is a need to reduce risk and variability associated with potential returns over project lifetimes in excess of 20 years, and thereby reduce reluctance by project investors to build LDES projects.

### 6. Lengthy development timeframes for grid-connected assets due to permitting and interconnection queues

While there are behind-the-meter LDES use cases, the majority of LDES assets will be grid-connected and therefore are subject to similar physical constraints as e.g., renewable power plants. In many markets, these interconnection timelines can extend to several years due to limitations in existing power networks that need to be resolved before new assets can be connected to charge and discharge from that local network. This challenge is particularly pronounced in markets that are targeting significant buildout of renewables, which is also where LDES will be most critical in the near-term to provide temporal flexibility.

Exhibit 3

## Current LDES technology deployment status

| Type | Technology | Market readiness today |
|---|---|---|
| **Mechanical** | Novel pumped hydro (PHS) | Commercial |
| | Gravity-based | Pilot |
| | Compressed air (CAES) | Commercial |
| | Liquid air (LAES) | Pilot (commercial announced) |
| | Liquid $CO_2$ | Pilot |
| **Thermal** | Sensible heat (e.g., molten salts, rock material, concrete) | R&D/pilot |
| | Latent heat (e.g., aluminum alloy) | Commercial |
| | Thermochemical heat (e.g., zeolites, silica gel) | R&D |
| **Chemical** | Power-to-gas-(incl. hydrogen, syngas)-to-power | Pilot (commercial announced) |
| **Electrochemical** | Aqueous electrolyte flow batteries | Pilot/commercial |
| | Metal anode batteries | R&D/pilot |
| | Hybrid flow battery, with liquid electrolyte and metal anode | Commercial |
| | Hybrid cathode batteries | Commercial |

Policy tools will be a key factor in overcoming these barriers and to enabling the LDES asset class, creating awareness and markets for novel technologies and stabilizing revenue, increasing investor and customer confidence, and enhancing revenue streams for LDES.

# 2.

# Policy toolbox

**This chapter introduces a policy "toolbox" for policymakers exploring the use of policy and regulatory instruments to support the commercial advancement of the LDES asset class.** It distinguishes between different types of policy and regulatory tools based on their intended functional objectives[9] and indicates whether each tool would typically be executed through policy or regulatory measures. This chapter also presents example mechanisms that have been applied to support energy storage or other clean energy technologies and that could be implemented to accelerate LDES deployment.

# Key considerations

## There are several key considerations for stakeholders developing policy and regulatory frameworks for LDES, many of which have been sucessfully applied to accelerate other clean energy technologies.

At the highest level, these considerations include:

1. **Recognize that the LDES asset class will evolve through several "horizons" of maturity and that different policy tools will be needed in each horizon:** The maturity of an asset class can be defined over three broad and generalized horizons over which project investor and customer return requirements, duration and level of policy support, sources of capital, and LDES technology costs will evolve.

   At a high level these horizons can be defined as (see Exhibit 4, next page):

   - **Horizon 1 – Market Creation:** the period when technologies are nascent and project costs are high due to limited economies of scale. In this horizon, substantial policy support is needed to lower initial technology costs, support initial manufacturing scale-up, build knowledge about technology use cases and value in full-scale projects, and launch the industry.
   - **Horizon 2 – Market Growth:** the period when technologies start to mature, initial commercial manufacturing lines are online, technology costs begin to decline, investor costs of capital come down and new investors and customers are comfortable entering the space to build projects at increasing scale with increasing tolerance for risk. Effective policy tools in this horizon often focus on adjusting to declining technology costs and steadily exposing technologies to underlying market forces with incumbent technologies that have already achieved full commercial scale.
   - **Horizon 3 – Market Maturity:** the period when technologies and supply chains are mature, new technologies have achieved economies of scale, costs of capital are normalized and a wide range of investors and customers are participating, and successful policy tools primarily focus on ensuring fair market competition and efficient market operations between mature asset classes.

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[9] Objectives that may include e.g., providing long-term signals to the industry, offering revenue or offtake support, reducing or removing operating costs and barriers. These functional objectives are further detailed in the next section for each type of tool.

Exhibit 4

## Level of policy intervention will evolve as the LDES market matures

| **Horizons** | **Market creation**<br>~ today-2025 | **Market growth**<br>~ 2025-2030 | **Market maturity**<br>~ 2030-2035 |
|---|---|---|---|
| **Description** | **First commercial projects after early pilots / demos, typically with high WACC required by equity investors** | **Increasing deployment volume and scale, cost and performance improvement, introduction of debt to reduce WACC** | **Fully de-risked technology with established funding mechanisms and investor pools, sustainable and lower WACCs** |
| **Level of support** | Comprehensive policy package providing revenue certainty and scale-up support | Significant support with increasing competitive tension to drive costs down and initial safeguarded market prices exposure | Revenue stabilization mechanisms are phased out with increased merchant exposure |
| **Potential policy mechanisms** | Mechanism with fixed annual payment that reflects full value of LDES systems<br>Contracts with long tenor (20-30 years) for revenue certainty<br>Grants supporting pilot projects<br>Storage capacity targets or procurement mandates | Introduction of Cap & Floor, or reformed Capacity Market (CM) providing premium for “clean” capacity<br>Targeted tenders with long-term contracts awarded | Evolved Cap & Floor, CM, or other mechanisms<br>Gradual but increased exposure to merchant project tail |
| **Sources of capital** | (Full) equity investment from technology providers<br>Some public funding (e.g., grants, loans, incentive schemes) alongside equity investment | Project-level financing, e.g., equity from large corporates such as integrated utilities and debt from commercial banks | Optimized financial instruments (equity and debt) provided by financial institutions and infrastructure investors, at cost-competitive levels given revenue certainty and low technology risk |

2. **Leverage a combination of policy tools to support the LDES asset class as the sector advances through maturity horizons:** A policy package that seeks to effectively drive increasing commercial maturity of a given asset class will necessarily leverage a combination of tools to address the barriers mentioned in the introduction. Different tools are designed to achieve different outcomes. Some types of tools are designed to provide a long-term outlook or signal to the market, while others are designed to provide short- and longer-term enhancement of returns and thereby ensure investment today and into the future. For example, an approach might be to combine R&D and pilot project funding, long-term storage capacity targets, and commercial-scale monetization mechanisms such as a long-term revenue floor (more details on these examples to follow in the next section). Since different LDES technologies vary in maturity today, suitable policies may also vary between technologies.

3. **Design policies that are stable but that can adjust flexibly over time:** An effective set of measures provide a stable outlook for support, whilst also maintaining transparency and flexibility to reasonably and predictably adjust as the market for LDES develops. The ability to adjust policy over time is critical to reflecting increasing scale and technological maturity, and to maintaining efficient markets and controlling program costs. At the same time, there is a need to provide a stable and predictable outlook so that the sector can attract the investment required to achieve scale.

4. **Include measures that improve LDES customer project viability:** Especially in the early days of market creation, spurring investment activity will require providing sufficient magnitude and certainty of returns to project investors, as well as assurance of loan reimbursement to banks. Magnitudes of returns are improved through mechanisms that provide pricing uplift or cost reduction, while certainty of returns is enhanced through long-term contracts or credit enhancements. These enhancements serve the needs of core potential LDES customer segments, such as power utilities, renewable project developers, etc. The level of required support can be allowed to wane as the technology class achieves economies of scale and viability increasingly becomes intrinsic.

5. **Prioritize feasibility of implementation:** Policy tools have variable track records of success and differ in their relative ease of implementation across technical, economic, and political dimensions, as well as their compatibility with broader clean energy programs in other sectors. It is essential to understand these complexities and how they affect the overall likelihood that a policy tool can be successfully deployed and will be effective in practice.
6. **Evaluate societal benefits and costs:** Policies should be aligned with a trajectory that leads to long-term societal benefits, including across environmental (e.g., emissions reduction), social (e.g., job creation and equity), and economic (e.g., energy cost reduction) dimensions.

These considerations have already been successfully applied and continue to be deployed to support other clean energy technologies. Examples include the creation of the solar photovoltaic or offshore wind industries. Indeed, a mix of targets, offtake agreements, and grants and incentives have been successful in accelerating commercialization of these clean energy technologies (refer to Exhibit 5 below for an illustrative selection).

> **The combination of different policies has already successfully supported the deployment of solar PV and offshore wind.**

Exhibit 5

### Similar policy considerations led to development of solar PV and offshore wind industries

| **Guiding principles** | **Case examples** (year of implementation) | |
|---|---|---|
| | **Solar PV** | **Offshore wind** |
| **Long-term procurement and capacity targets** | 🇩🇰 2030 RES target set (1998)<br>🇺🇸 State Renewable Portfolio Standards (1983) | 🇩🇰 20-year FiP (2008)<br>🇩🇪 Offshore wind target for 2045 (2021)<br>🇬🇧 Offshore wind target for 2030 (2021) |
| **Offtake agreements / revenue contracts** | 🇩🇪 20-year FiT granted (2000) | 🇺🇸 Offtake agreements (2021)<br>🇬🇧 Contract for Difference (CfD) (2017) |
| **Grants and incentives** | 🇩🇪 Prioritized access to grids; state-owned development bank KfW grants subsidized loans (2000) | 🇳🇱 Centralized development, funding of grid connection costs (2014)<br>🇺🇸 Investments in supply chain (2021) |

# Types of policy and regulatory tools

This report has assembled a toolbox of 20 potential tools, each selected based on existing precedent in shaping energy markets and deploying clean energy technologies.

**These mechanisms are intended to provide a comprehensive overview of mechanisms that can support rapid commercialization of clean energy technologies like LDES.** They are, however, not intended to be an exhaustive review of all potential options, nor a reimagination of energy markets as may one day be contemplated as systems converge on net-zero carbon emissions. These mechanisms are also offered as a means of complementing, not substituting for, continued emphasis on development of robust pricing signals for storage assets in existing market frameworks (e.g., balancing, intra-day, and day-ahead).

Various regions and jurisdictions are already experimenting with a combination of these tools to support the broader deployment of grid-scale energy storage, including LDES. Please refer to the Appendix for a snapshot of the tools being combined in selected regions.

## Long-term market signals

**The policy tools below are a selection of approaches that have been used to develop markets for other new clean energy technologies by providing favorable market conditions in the long term.** These options have succeeded at defining and facilitating a path to fulfilling a long-term vision of the energy system. They can provide clarity about long-term state or federal policy and decarbonization ambition as well as stimulate deployment of technologies required for this transition, including storage. Further, these tools provide the stable foundation necessary at the market creation stage to signal that the private sector should make initial investments necessary to develop new technologies, and associated supply chains, to bring new technologies to the market in increasing volumes. The group consists of existing measures that include:

Carbon pricing and greenhouse gas reduction targets

Grid planning

Phase-out of fossil fuel subsidies

Procurement targets

Renewable energy targets

Storage capacity targets

### Carbon pricing and greenhouse gas reduction targets

**A selection of pricing mechanisms for greenhouse gas emissions, in the form of taxes or trade-able certificates, that aim to reduce these emissions by imposing a cost on fossil fuel consumption and that may be implemented either as regulation or policy[10].** These tools may enhance the competitiveness of LDES solutions because they impact Levelized Cost of Energy (LCOE) of marginal generation plants, which are typically fossil-fired (e.g., gas turbines). This in turn increases the market bid prices required by these marginal generators to cover their generating costs, and therefore can also increase the spread between off-peak and peak electricity market prices that LDES assets can capture. Notably, this benefit signal is strongest in the earliest days of LDES market formation (Horizon I), when grids have higher penetrations of fossil generation, especially as marginal generation resources. However, while carbon pricing may improve LDES business case economics, it does not address volatility of project revenues since underlying carbon prices remain variable in most carbon markets.

### Grid planning

**Transmission and distribution network companies, including unbundled Transmission System Operators (TSOs), Independent Transmission Companies, Distribution System Operators (DSOs)[11] or vertically-integrated utilities, may as part of their network planning activities model LDES assets in power flow simulations as an alternative to conventional network reinforcement[12] and as a solution for provision of ancillary services[13].** Furthermore, LDES can be included comprehensively in an Integrated Resource Plan (IRP) to ensure that storage solutions are also considered when making generation capacity decisions. Inclusion of LDES in grid planning is critical for ensuring that a range of novel and incumbent technology options are considered – and a least-cost portfolio of technologies selected – for an optimal power system outcome that considers the synergies between these assets and the power grid. Regulatory oversight to ensure that such alternatives to network development are reasonably considered as part of network development business cases is key, as are regulatory or market frameworks for procuring services from or owning these assets.[14]

### Phase-out of fossil fuel subsidies

**Removal of fossil-fuel subsidies works in similar fashion to carbon pricing by leveling the playing field between emitting, fully-mature, fully-scaled incumbent resources and new technologies like LDES that are non-emitting and have not yet achieved full commercial maturity.** Existing subsidies for the fossil fuel industry often include the provision of special loans with low interest rates (reducing cost of capital), preferential tax policies or credits (improving returns), or other advantages such as accelerated permitting for construction or inexpensive leases for land. Subsidies (or the removal thereof) are typically policy measures (as opposed to regulatory measures).

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[10] As an example, the United Kingdom has established legally-binding regulatory "Carbon Budgets" that aim to limit carbon dioxide emissions from its economy as it drives toward net-zero by mid-century. On the other hand, in other jurisdictions such as Australia different governments have experimented with carbon taxation policy as a means of driving down emissions.

[11] Where applicable; many major distribution network companies own and operate assets up to 110 kV or higher, depending on the geography.

[12] Network reinforcements may include constructing new or reconductoring existing transmission lines, uprating the voltage of transmission lines in selected corridors, replacing transformers, etc.

[13] As an example, these entities may contract for grid stability, which is enhanced through procurement of inertial response, voltage/reactive power support, or delivery of short circuit current.

[14] In the case of unbundled power markets, TSOs are not typically permitted to own and earn a rate of return on storage assets.

**Procurement targets**

**A policy tool that stipulates or mandates purchases of LDES assets by a certain buyer or type of buyer. Procurement targets might be established by the entity itself or set for the entity by a governing body.** These entities may include government-owned bodies that procure LDES for specific applications.[15] Procurement targets can provide a stable source of long-term demand and thereby de-risk investment by the private sector into manufacturing capacity and project development.

**Renewable energy targets**

**Legislated, regulatory targets for renewable energy supply (e.g., as a power capacity or volumetric generation target) support deployment of renewable generators and by extension resources like LDES that provide the flexible capacity required to balance systems with majority renewable energy share.** Renewable energy targets frame the magnitude and urgency of the need for LDES. A more targeted variation may include renewable energy targets for certain periods, e.g., a certain renewable share on an hourly basis.

**Storage capacity targets**

**Legislated or regulatorily-defined targets for storage capacity, structured in similar fashion to renewable energy targets, provide a clear demand signal informing how much storage will be required in each jurisdiction, in a given geography.** Such targets therefore offer a roadmap for the sector, driving investment and procurement decisions by power utilities in that region. Targets may also define capacity amounts by differing durations, to ensure an optimal buildout of flexibility.

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[15] As is the case with US President Biden's Executive Order from December 2021 which set a target of 100% "carbon pollution-free" electricity use in federal infrastructure by 2030, including 50% on "24/7 basis".

## Revenue mechanisms

**Revenue mechanisms support LDES business cases by improving expected returns and stabilizing the variability of these returns.** The tools described in this section may be added to existing market designs and implemented as technology-agnostic measures or they may include dedicated instruments that guarantee offtake payments for LDES assets. Many of the mechanisms outlined are compatible with – and indeed can enhance – existing energy markets and are designed to reduce the variability of revenue streams associated with wholesale exposure. The revenue support mechanisms considered are:

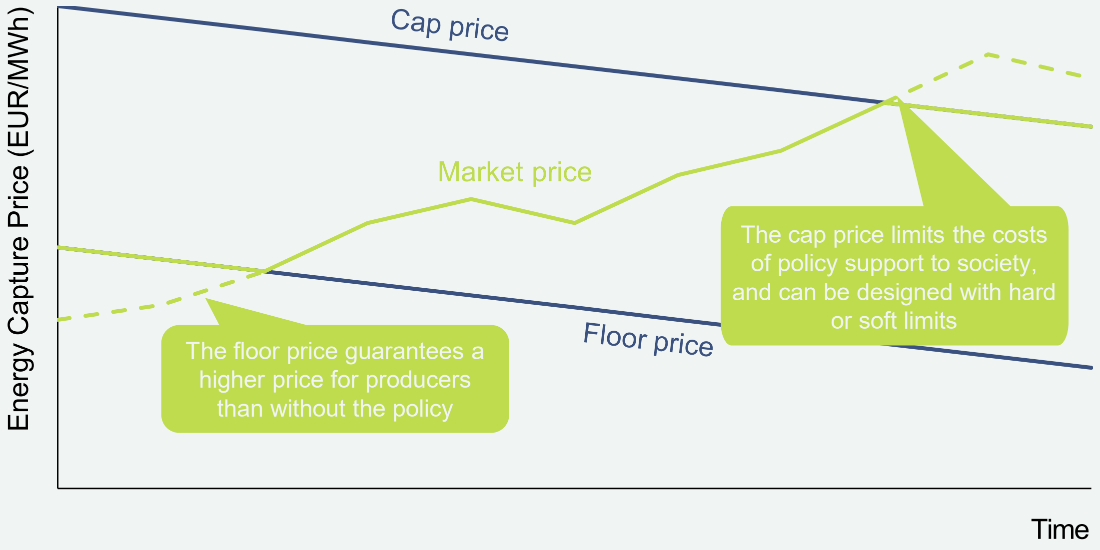
- Cap and floor
- Capacity market
- CFD
- Hourly energy attribute certificates
- Long term bilateral contract for balancing / ancillary services
- Nodal & locational pricing
- Regulated asset base
- 24/7 clean PPA

### Cap and floor

**Multi-year contract with a defined minimum (the "floor") and maximum (the "cap") level of energy capture price (e.g., EUR/MWh) for the asset owner, also commonly referred to as price corridor.** Should the energy price captured by the asset fall below the floor, the asset receives the floor price. Similar dynamics apply for the cap, except in reverse, with a "hard" cap representing the maximum energy price that can be received to protect the offtake entity's cost exposure (excess revenues are returned to the offtake entity). The intent of these caps is to limit societal exposure over the course of the policy support. Like a Contract for Difference (CfD, see below), a Cap & Floor would typically be administered and funded by a government vehicle, supported from taxes and fees imposed on the consumption of electricity. If implemented with a "soft" cap, a portion of the capture value above the cap could be shared with the asset (e.g., in pre-set diminishing portions as energy prices increase above the cap) to efficiently transfer price signals and reward assets for participation at times of greatest system need. The floor price would be set such that it enables competitive debt financing for the asset, and average payouts between cap and floor price would nominally offer returns sufficiently attractive to drive project investment. Such mechanisms are currently implemented for interconnector transmission lines in the UK and commonly applied to provide price controls for monopoly assets. Exhibit 6 illustrates the effect of a Cap & Floor on LDES prices.

Exhibit 6

## A Cap & Floor provides an upper and lower bound for the market price



A notable variant of the Cap & Floor is simply a "Floor" without a cap, offering unlimited financial upside. Such a "Floor" could also be implemented as a fixed revenue contract (as opposed to a volumetric remuneration), effectively becoming a Minimum revenue contract (see illustrative example in inset below).

> **Minimum revenue contract:** A long-term supply agreement, e.g., with the system operator, in which the asset is offered a minimum annual revenue for a bundled set of negotiated services (e.g., energy, capacity, balancing, inertia, voltage / reactive power support, restoration, etc.).

| | |
|---|---|
| **Contract length** | Multi-year contract, minimum 10 years in length (if not longer, to cover project lifetimes that can be in excess of 20 years for some technologies) |
| **Description** | The revenue requirement represents the floor (minimum) the service provider would earn with potential upside from additional utilization, favorable price action, or top quartile performance |
| **Contract award** | Service providers would bid an annual floor revenue value for a unique bundle of services |
| **Advantages** | **Holistic compensation:** Multi-service revenue floor comprehensively remunerates service provider for full value of offerings<br>**Performance optimization:** Asset operator has incentives to optimize operation within the set of contracted services<br>**Compatible with auctions:** Competitive bidding process would drive lower costs and encourage innovation |
| **Disadvantages** | **Bid evaluation:** The system operator would need to evaluate and compare bids from service providers that combine different services at different price points<br>**Performance benchmarking:** The system operator would need to benchmark performance across ESS to offer upside to top quartile<br>**Distrust of market:** Some stakeholders may not trust revenue arrangements where savings are not always shared with societal stakeholders |

**Capacity market**

**Long-term contract[16] remunerating a facility for access to its power capacity (i.e., a payment per MW of power capacity available for dispatch).** The aim of this market mechanism is to secure sufficient capacity in the power system to meet and maintain long-term system reliability and stability. By providing remuneration that is directly proportional to capex, capacity payments enhance the economic business case for new generators and ensure a secure, minimum return on capital. The CM may be enhanced through additional stipulations, such as a premium for zero-carbon (or a maximum emission factor per MWh, as was deployed in EU regulation[17]) dispatchable generation capacity, or by including capacity derating factors that provide different levels of compensation for assets with varying levels of duration capability.[18]

**CFD**

**Multi-year contract with a dispatch "strike price" allowing investors in the asset to fix a price per MWh in the energy market.** Where captured energy prices fall below the strike price, the facility is compensated for the difference by the administrating body; simultaneously, the facility must return any value captured above the strike price. As a result, CfDs provide long-term fixed revenue signals, with potential to enhance energy market revenues and eliminate substantial risk for investors. Exhibit 7 illustrates the effect of a CfD.

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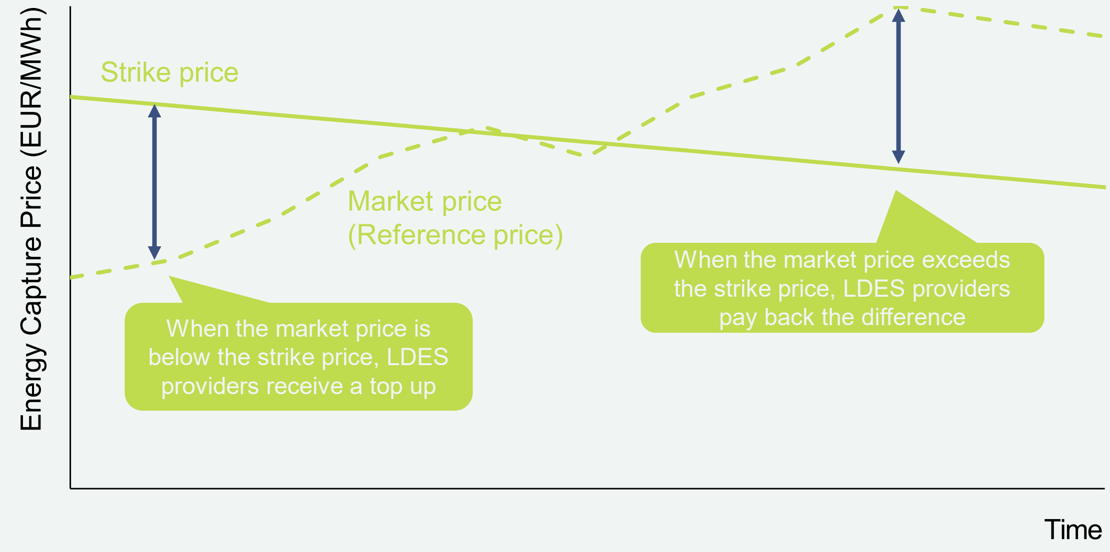
[16] Typically range from around five years to longer i.e., 15 years for new T-4 capacity in the UK.

[17] The 4th energy package titled "Clean energy for all Europeans" limits emissions to 550 kg/MWh starting in the early 2030's.

[18] In many markets, there are either thresholds for duration (e.g., CAISO and NYISO in the US have a minimum four-hour requirement) or derating factors (e.g., concept of Effective Load Carrying Capability or ELCC in California, also implemented in the UK for energy storage, with shorter duration batteries typically seeing higher derating i.e., lower compensation per unit of capacity).

Exhibit 7

## A CfD only pays a subsidy if the market price is below the strike price



However, because the CfD is designed to incentivize maximal output given its structure as a remuneration per MWh (volumetric energy sales), the tool may not support system-optimal dispatch unless there are established and robust flexibility / balancing markets. A variant on the energy CfD is a Carbon Contract for Difference (CCfD), as is being explored to support hydrogen use cases (see inset for illustration below).

> **Carbon Contract for Difference (CCfD):** a long-term government contract providing additional remuneration for LDES assets defined based on a carbon strike price per ton (i.e., the marginal cost of carbon abatement) and the carbon savings from the use of these assets.

| | |
|---|---|
| **Contract length** | Multi-year contract, minimum 10 years in length (if not longer, to cover project lifetimes that can be in excess of 20 years for some technologies) |
| **Description** | The mechanism would provide a payment per ton of carbon dioxide that is equivalent to the difference between the strike and prevailing carbon price (e.g., in EU ETS). Operation could be similar to a standard CfD arrangement, wherein if the prevailing market price exceeds the strike price, the contractual counterparty would return excess revenues. Carbon savings from the use of LDES could be measured as the delta between emissions from charging (zero if sourcing directly from RES) and discharging (i.e., the emission rate from the displaced marginal generator) |
| **Contract award** | Contracts could be awarded via reverse auctions with service providers bidding a carbon strike price per ton |
| **Advantages** | **Industry analogues:** CCfD is being explored as tool to support green hydrogen use cases; standard CfD more broadly well understood as tool for make-whole payments (e.g., UK offshore wind)<br>**Economic premise:** Concept of marginal abatement cost of carbon is well understood |
| **Disadvantages** | **Carbon accounting:** Likely complex, as may require calculating the grid emissions factor or emission rate of marginal generator at time of charging and/or discharging<br>**Carbon market integration:** Would require integration and coordination with underlying carbon pricing markets (if in existence) to calculate the delta between market and strike prices of carbon |

**Hourly energy attribute certificates**

**Traditional Energy Attribute Certificates (EACs) consist of certificates that indicate a given unit of energy production was generated from renewable resources.** EACs are typically designed as liquid assets that can be traded between generators and energy consumers (principally commercial and industrial customers, intermediary power retailers, and with possible extension to small-scale or residential consumers). They are used by energy consumers to meet mandated or voluntary renewable energy procurement targets, providing more precise incentives than annual targets.[19] Hourly EACs would require amendment of these existing EAC schemes to assign a timestamp to certificates for renewable energy production, allowing energy consumers to move from volumetric matching of power consumption on an annual basis to an hourly basis. Such an EAC scheme could be accompanied by centrally-mandated procurement targets, liquid spot and derivative markets, and long-term supply and offtake contracts.

**Long term bilateral contract for balancing / ancillary services**

**Multi-year contracts between LDES operators/owners with grid operators (TSOs/DSOs) for delivery of various ancillary services focused on maintaining power quality and reliability.** Various mechanisms already exist today to compensate for ancillary services relating to frequency regulation, reactive power and voltage control, spinning reserves, restoration, or congestion management.[20] Long duration storage is needed to serve system reserves, restoration, and congestion management functions in a decarbonized grid. If these services could be contracted in long-term arrangements they could provide asset owners with a predictable revenue stream.

**Nodal & locational pricing**

**Power production and consumption pricing signals provided at the resolution of individual transmission nodes, considering both energy supply and transmission costs.** The objective of nodal markets[21] is to provide granular pricing signals to incentivize investment. This pricing granularity stands in stark contrast to zonal markets, which are simpler to administer (especially in terms of technical and operational software) and in which an entire electrical region receives and pays the same price for electricity. Nodal systems are inherently technology-agnostic, but could support a potential uplift in returns for strategically-located LDES assets (e.g., within a congested electrical boundary, or with access to excess renewable generation) able to capture higher spreads available in a nodal system. While nodal pricing signals could enhance returns, they do little to reduce long-term investment risks, given that any changes to network topology, generation portfolio, or consumption patterns would in turn affect power prices.

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[19] Massachusetts introduced the Clean Peak Standard, an hourly renewable portfolio standart with a similar effect as hourly energy attributes.

[20] Examples include the Stability Pathfinder (for inertia provision) or restoration programs administered by National Grid Electricity System Operator in the UK, which offer respectively five- and three-year contracts for these ancillary services.

[21] Examples of nodal power markets include CAISO, PJM, and ERCOT in the US. Examples of zonal markets include those operated by European TSOs or the Transmission Network Service Providers (TNSPs) in Australian states.

**Regulated asset base**

**Government-approved contracts for regulated monopoly utilities to deploy energy assets and receive guaranteed returns on these investments (commonly used for monopoly electric network infrastructure).** The RAB is designed to adequately compensate investment into large-scale infrastructure whilst also protecting consumers from excessive costs. This model is the classic regulatory structure for incentivizing asset development of transmission and distribution networks (e.g., European TSOs) and may also be applied by vertically-integrated utilities to directly procure, own, and operate (and earn returns on) LDES assets.

**24/7 clean PPA**

**Also commonly known as "shaped PPAs", "dispatchable" or "round-the-clock" PPAs, these are multi-year contracts defining an energy offtake price to "hybrid" installations of renewables and flexibility systems.** The term "24/7" refers to the capacity for the assets to supply time-matched clean power to the load. There are different "shapes" of PPAs, depending on how closely consumption is matched with generation (e.g., 80% of hours vs. 90% or 100% hours, or for peak hours only). Such contracts could be awarded in public tenders or via bilateral contracts, and could also be applied to standalone energy storage installations. The tool offers both pricing uplift potential as well as long-term revenue certainty. In order for 24/7 clean PPAs to incentivize the deployment of enabling decarbonization technologies like LDES, industry-agreed quality standards need to be defined.[22]

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[22] Please refer to the LDES Councils publication from May of 2022 titled A path towards full grid decarbonization with 24/7 clean Power Purchase Agreements available on ldescouncil.com

## Direct technology support and enabling measures

**Direct technology support and enabling measures decrease barriers to new technology adoption or create favorable environments to deploy nascent technologies.**

### Direct technology support

**Grants and incentives**

**Sandboxes**

**Targeted tenders**

### Enabling measures

**Investment de-risk mechanisms**

**Market rules**

**Technology standards**

### Direct technology support include:

**Grants and incentives**

**Dedicated, non-repayable funds or discounts that are allocated to support asset CAPEX or OPEX, and thereby drive improved business cases.** Funding mechanisms may involve third party partners like banks or public institutions and focus on providing targeted support to projects satisfying technical and operational requirements established by the funding institution(s). Incentives may also include e.g., tax credits for investment, production, or manufacturing.

**Sandboxes**

**Creation of a piloting environment with flexible or relaxed regulation that permits the initial deployment and testing of innovative products and services at a relevant commercial scale with minimal barriers.** Such approaches could offer impactful learning opportunities for a wide selection of technologies and thereby allow the highest performing solutions to mature in a learning-focused environment (knowledge reporting and dissemination are typically core aspects of these arrangements).

**Targeted tenders**

**Procurement mechanisms targeting a specific class of assets by setting clear technology requirements, such as a given duration of storage required.** Such mechanisms could leverage auctions to drive competitiveness, with requirements sufficiently specific to support the target asset class.

## Enabling measures include:

**Investment de-risk mechanisms**

**Policy mechanism that offers blended finance, including public and/or public-private funding to finance, build, and operate projects.** The tools, also referred to as credit enhancement mechanisms, lower investment risk to private investors by reducing project cost of capital (thereby enhancing returns) and providing first loss guarantee.

**Market rules**

**Adaptations to existing, regulated market rules or introduction of new rules that create an opportunity for new asset classes to participate in existing markets.** Often considered an "enabling policy", these modifications can remove obstacles and drive access to existing markets that can directly improve LDES project economics and create a level-playing field with other assets in the electricity system.

**Technology standards**

**Definition of minimum environmental, technical, or other standards for different asset classes that support a desired level of operational performance while remaining technology-neutral.** Similar to market rules, technology standards are a regulatory enabling measure to provide an accessible market for LDES participation. These same standards can inform customer procurement processes, such as those relating to public tenders and RFPs.

# Policy tool assessment framework

A qualitative assessment framework was developed to compare different policy options on seven indicators that consider impact of the tools on project viability, ease of implementation, and long-term effectiveness in delivering a secure, reliable, affordable, and low-carbon energy future.

Exhibit 8

## Overview of key criteria and indicators applied as part of qualitative assessment

| Criteria | Indicator | Description of indicator |
|---|---|---|
| **Viability enhancement**<br>Ability of tool to enhance business case for customers and investors | ⓐ Enhancement of returns | ○ Can the tool **improve the economic business case** for LDES? |
| | ⓑ Reduction of project risk (spread on returns) | ○ Can the tool **reduce the risks to customers and investors** of funding LDES projects? |
| **Ease of implementation**<br>Relative effort and complexity of deploying tool | ⓒ Relative effort / complexity of integration | ○ How **easy is the tool to implement, including integration** with existing systems, markets, and policies? |
| | ⓓ Track record and industry precedent | ○ How strong is the **track record of the tool** in supporting deployment of energy technologies? |
| **Long-term effectiveness**<br>Flexibility of tools to deliver long-term, sustained impact | ⓔ Adaptability as technology matures | ○ How **flexible is the tool to be adapted** to maintain efficient support as the technology class matures? |
| | ⓕ Cost-effectiveness | ○ Does the tool create **sufficient value for money** that outweigh the burden and potential costs of implementation? |
| | ⓖ Ability to accelerate decarbonization agenda | ○ Does the tool **support a broader decarbonization agenda** and environmental progress? |

### Criterion #1: Viability enhancement

**Viability enhancement refers to the ability of a tool to enhance the business case economics for LDES and reduce customer and investor risk.** To address the fundamental economic challenges associated with deploying capital-intensive, early-stage solutions, a key consideration will be how to improve financial viability and accessibility for customers and the investment community. There are two important considerations: firstly, the absolute return on an investment (in terms of magnitude), and secondly, the variability or risk associated with that return. Simply delivering an uplift to the average return of a business case is insufficient if there is still considerable risk around whether that return will materialize. Hence, both improvement of return and certainty of return are important dimensions of overall project viability enhancement.

a Enhancement of returns: Can the tool **improve the economic business case for LDES?**

b Reduction of investor risk (spread on returns): Can the tool **reduce the risks to customers and investors** of funding LDES projects?

### Criterion #2: Ease of implementation

**Ease of implementation describes the relative ease or difficulty of effectuating a policy tool.** In practice, this involves understanding the complexities of integrating a particular policy tool, where these complexities could be technical in nature (how does this tool impact existing system operation, what new IT systems would be required to implement), economic (how will this tool interact with other tools already in effect, how can distortion be avoided), or political (what is the perception of this tool, what is the process for getting it implemented). The track record of the tool and its history of deployment for similar applications in other jurisdictions and/or for analogous clean energy technologies should also be considered, given the value in leveraging best practices and experiences where applicable. For each jurisdiction, the existence of similar energy policies can also affect the ease of implementation (e.g., if a CfD already exists for a source of renewable energy, then there is a precedent and institutional knowledge supporting deployment of a similar tool for LDES).

c Relative effort / complexity of integration: What is the **complexity of implementation and further integration** of the tool within the energy regulatory environment?

d Track record and industry precedent: Are there **examples of successful implementation** of that tool for similar applications?

### Criterion #3: Long-term effectiveness

**Long-term effectiveness describes the policy's adaptability over time, cost effectiveness and broader effect on decarbonization.** Ultimately the mission of a given policy tool is to deliver sustained impact and support as technology matures, balancing progress toward decarbonization goals and the socioeconomic impact (especially the cost of administering the tool). As such, the adaptability of the tool to be adjusted with increasing technology maturity will be key, along with the long-term economic net benefit calculus (avoidance of distortion, expense of supporting schemes, job creation, economic dividends). A policy tool is also likely to be more durable if it supports progress toward broader decarbonization and the overall energy transition.

e Adaptability as technology matures: What is the **level of flexibility in terms of potential adjustments** to the mechanism operation?

f Cost-effectiveness: Does the tool create **sufficient value for money** that outweigh the burden and potential costs of implementation?

g Ability to accelerate decarbonization agenda: Does the tool **support acceleration of LDES and renewables deployment?**

# Assessment of identified tools

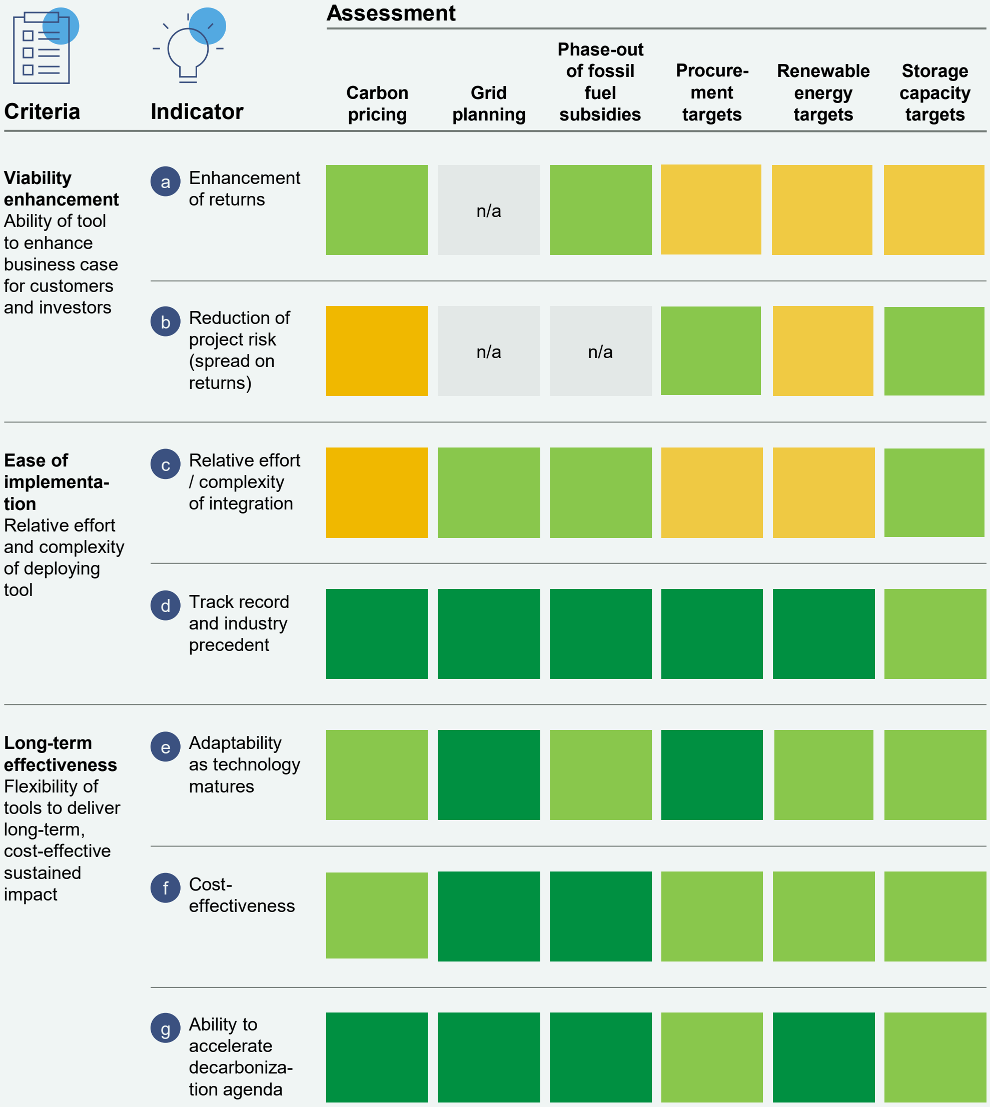
## A wide range of time-tested policy and regulatory tools could potentially be applied to the LDES sector.

The elaborated rationale for the scoring of each individual tool is presented in the Appendix section. The key highlights from the assessment across the three types of tools are summarized in this next section.

Exhibit 9

### Summary of assessments for long-term market signals

- 🟥 Weak
- 🟨 Mixed
- 🟩 Fairly strong
- ■ Very strong



| Criteria | Indicator | Carbon pricing | Grid planning | Phase-out of fossil fuel subsidies | Procure-ment targets | Renewable energy targets | Storage capacity targets |
|---|---|---|---|---|---|---|---|
| **Viability enhancement** Ability of tool to enhance business case for customers and investors | ⓐ Enhancement of returns | 🟩 | n/a | 🟩 | 🟨 | 🟨 | 🟨 |
| | ⓑ Reduction of project risk (spread on returns) | 🟨 | n/a | n/a | 🟩 | 🟨 | 🟩 |
| **Ease of implementation** Relative effort and complexity of deploying tool | ⓒ Relative effort / complexity of integration | 🟨 | 🟩 | 🟩 | 🟨 | 🟨 | 🟩 |
| | ⓓ Track record and industry precedent | ■ | ■ | ■ | ■ | ■ | 🟩 |
| **Long-term effectiveness** Flexibility of tools to deliver long-term, cost-effective sustained impact | ⓔ Adaptability as technology matures | 🟩 | ■ | 🟩 | ■ | 🟩 | 🟩 |
| | ⓕ Cost-effectiveness | 🟩 | ■ | ■ | 🟩 | 🟩 | 🟩 |
| | ⓖ Ability to accelerate decarbonization agenda | ■ | ■ | ■ | 🟩 | ■ | 🟩 |

## Long-term market signals:

- **Carbon pricing** is an effective tool for improving LDES project returns and setting a broader level-playing field for decarbonization but offers limited stability in terms of revenue outlook given the underlying uncertainty of future carbon pricing.
- **Long-term renewables, storage, and procurement targets** can be relatively simple tools that increase awareness of market participants and offer clarity about the longer-term policy direction – both being important elements to spur LDES deployment – and can therefore have an impact on viability by spurring increased project demand. Storage and procurement targets can have a more direct impact on LDES if they include specifications and mandates for longer-duration forms of storage.
- **All long-term system planning tools** have demonstrated success delivering sustained impact and accelerating the decarbonization agenda, whilst simultaneously being sufficiently adaptable as technologies and markets mature.

Exhibit 10

### Summary of assessments for revenue mechanisms

🟥 Weak
🟨 Mixed
🟢 Fairly strong
🟩 Very strong

| | | Assessment | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Criteria** | **Indicator** | **Cap & Floor** | **Capacity market** | **Contract for difference** | **Hourly Energy Attribute Certificates** | **Long-term balancing services** | **Nodal or locational marginal pricing** | **Regulated asset base** | **24/7 clean PPA** |
| **Viability enhancement** Ability of tool to enhance business case for customers and investors | ⓐ Enhancement of returns | 🟩 | 🟨 | 🟩 | 🟢 | 🟢 | 🟢 | 🟩 | 🟩 |
| | ⓑ Reduction of project risk (spread on returns) | 🟢 | 🟢 | 🟩 | 🟨 | 🟩 | n/a | 🟩 | 🟩 |
| **Ease of implementation** Relative effort and complexity of deploying tool | ⓒ Relative effort / complexity of integration | 🟢 | 🟢 | 🟨 | 🟢 | 🟨 | 🟥 | 🟨 | 🟢 |
| | ⓓ Track record and industry precedent | 🟩 | 🟩 | 🟩 | 🟩 | 🟢 | 🟩 | 🟩 | 🟩 |
| **Long-term effectiveness** Flexibility of tools to deliver long-term, cost-effective sustained impact | ⓔ Adaptability as technology matures | 🟢 | 🟢 | 🟩 | 🟩 | 🟢 | 🟩 | 🟩 | 🟩 |
| | ⓕ Cost-effectiveness | 🟢 | 🟢 | 🟢 | 🟩 | 🟢 | 🟩 | 🟢 | 🟢 |
| | ⓖ Ability to accelerate decarbonization agenda | 🟢 | 🟨 | 🟢 | 🟢 | 🟨 | 🟨 | 🟢 | 🟢 |

## Revenue mechanisms:

- **Nodal or locational marginal pricing** scores high for creating net socio-economic benefits given that its pricing signals optimize total energy delivery cost and inherently account for network congestion. LMPs may also provide additional remuneration for LDES and support geographical deployment of LDES to the nodes where system needs are greatest. However, this type of system is complex to implement and may not drive lower project investment risks.
- **RAB, cap & floor, minimum revenue contract, 24/7 clean PPA, contract for difference, and long-term contracts for balancing services** are tools that directly target project returns and risk, given their common structure as long-term offtake agreements. All of the mechanisms have demonstrated precedent (except the minimum revenue contract). While they all achieve a similar outcome, there are subtle nuances that differentiate the mechanisms regarding how flexible and cost-efficient they are:
  - For example, a Cap & Floor would offer a range of offtake prices and therefore potentially introduce greater variability of returns versus a fixed price arrangement such as CfD. All mechanisms that remunerate based on volumes of energy delivered (e.g., C&F, 24/7 clean PPA, and CfD) also incentivize output-maximizing behavior, which could be at odds with an optimal system-level outcome, especially where flexibility or balancing markets are underdeveloped to offer alternative pricing signals. By removing or "softening"[23] a Cap, the pricing signals in the market can be transferred to the asset and its owner/operator incentivized to capture higher price events.
  - Cost effectiveness could also be impacted by how these mechanisms are administered. As an example, traditional C&F mechanisms were designed to provide pricing corridors for monopoly assets (e.g., interconnectors) with limited competitive pressure while the CfD strike prices tended to be awarded via competitive reverse auction. These differences could lead to variable value to society over time, especially given that reverse auctions typically lead to lower costs compared to price controls established centrally.
- **Hourly EACs** are another revenue mechanism that has the potential to enhance LDES business cases by providing an additional revenue stream for project developers from activities related to trading of these certificates. However, unless structured as long-term offtake agreements (similar to PPAs), hourly EACs are subject to market forces of supply and demand, which introduces variability in offtake price and therefore in returns for project investors. While creating sufficient liquidity in hourly EAC spot/derivative products will be challenging, hourly EACs as a mechanism benefit from broad familiarity with the concept of a Renewable Energy Credit (REC), which has an established track record in the deployment of renewable generation. Further, hourly EAC prices are driven by supply and demand, are not set by any central body and require little to no regulation, and do not require public funding as the costs are paid by electricity consumers. These mechanisms can have high socio-economic benefits and are also highly adaptable (as prices are driven dynamically by supply and demand balances).
- **Capacity markets,** although a popular solution for remunerating generating capacity with an established track record of long-term agreements, may not provide sufficient economic support for LDES given the likely requirement to compete with conventional, fully-scaled technologies with lower relative capital costs. A CM could be modified to offer a premium for lower carbon solutions (which could in theory be sufficiently high to preclude the need for significant additional revenue stacking) or to require a clean electricity standard[24], in which case the mechanism could also drive greater carbon impact over time.

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[23] As a reminder, a "soft" cap is one wherein the asset owner retains a portion of the economic upside above the cap price level.

[24] In the EU, a maximum carbon emissions factor of 550 g/kWh is permissible for participation in CMs.

Exhibit 11

## Summary of assessments for direct technology support and enabling measures

- 🟥 Weak
- 🟨 Mixed
- 🟩 Fairly strong
- 🟢 Very strong

| Criteria | Indicator | Assessment | | | | | |
|---|---|---|---|---|---|---|---|
| | | Direct technology support | | | Enabling measures | | |
| | | Grants | Sandboxes | Targeted tenders | Investment de-risk mecha-nisms | Market rules | Technology standards |
| **Viability enhancement**<br>Ability of tool to enhance business case for customers and investors | ⓐ Enhancement of returns | 🟩 | n/a | 🟩 | 🟩 | 🟩 | n/a |
| | ⓑ Reduction of project risk (spread on returns) | 🟨 | n/a | 🟢 | 🟩 | 🟨 | n/a |
| **Ease of implementation**<br>Relative effort and complexity of deploying tool | ⓒ Relative effort / complexity of integration | 🟩 | 🟢 | 🟨 | 🟢 | 🟥 | 🟨 |
| | ⓓ Track record and industry precedent | 🟢 | 🟩 | 🟩 | 🟢 | 🟢 | 🟢 |
| **Long-term effectiveness**<br>Flexibility of tools to deliver long-term, cost-effective sustained impact | ⓔ Adaptability as technology matures | 🟩 | 🟢 | 🟢 | 🟢 | 🟩 | 🟢 |
| | ⓕ Cost-effectiveness | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 |
| | ⓖ Ability to accelerate decarbonization agenda | 🟩 | 🟨 | 🟩 | 🟩 | 🟩 | 🟨 |

## Direct technology support and enabling measures

- **Targeted tenders, grant/incentives, investment de-risk mechanisms** are effective tools for selective financial support for nascent LDES technologies. However, some of these policies only support the build out of LDES and not necessarily the dispatch. Investment de-risking directly addresses the barrier from investor risk perception and can have a substantial impact on project costs given high initial CAPEX (see calculations in Chapter 3).
- **Amended market rules** can be a key enabler for LDES by decreasing barriers for operation, thereby driving financial efficiency and accelerating LDES market growth. Particularly where existing rules discriminate against the LDES asset class based on historic definitions, amendments can accelerate LDES deployment with moderate effort and low costs. However, the processes for instituting substantial rule changes and their integration with existing systems may be less straightforward.
- **All direct technology support and enabling measures** are relatively well-known tools that have been deployed globally. At the same they are adaptable and, if constructed properly, could be catalysts for system decarbonization. However, in the case of grants / incentives in particular, scalability could become an issue given constraints to sources of funding support.

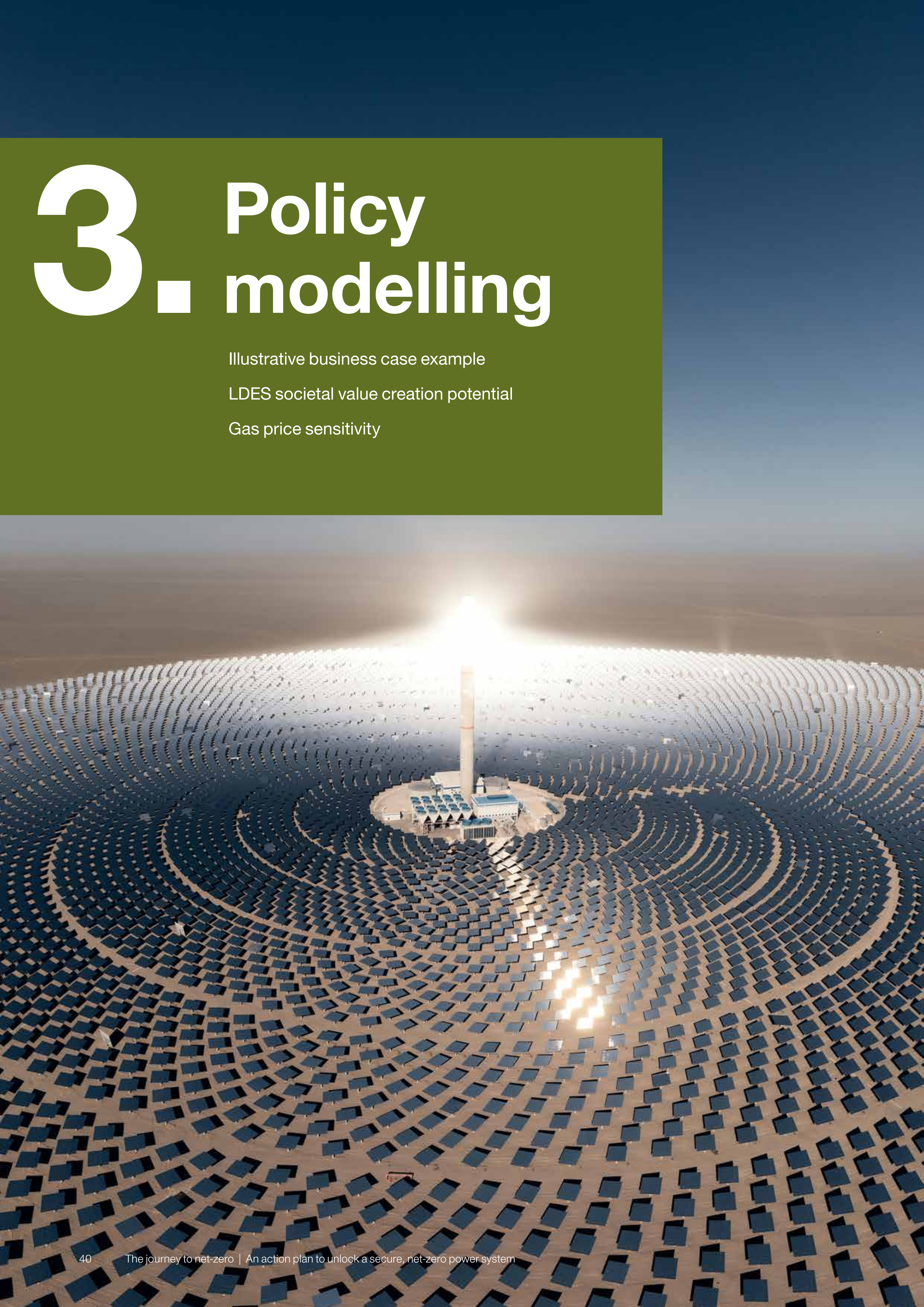
**Policymakers have a wide range of strong-performing mechanisms to support acceleration of the LDES sector and de-risk the energy transition.** As discussed in the preceding sections, many of the mechanisms assessed exhibit fairly strong or very strong ratings across the considered indicators. Revenue mechanisms have the highest share of very strong ratings due to their direct impact on project financial viability, addressing a key near-term barrier in the sector, but long-term market signals and direct technology support and enabling measures effectively address other market barriers.

# 3. Policy modelling

Illustrative business case example

LDES societal value creation potential

Gas price sensitivity



**A simplified business case model was developed to illustrate the potential impact of policy intervention on project viability,** as measured by increased Net Present Value (MPV) and Internal Rate of Return (IRR). The analysis also considers the societal value creation potential from avoided generation and transmission savings that LDES deployment can unlock.

**This business case evaluation was performed in Excel via the construction of a simplified discounted cash flow model.** It includes:

- Project revenue streams: energy arbitrage and ancillary services
- Project costs: capital and operating, including charging costs
- Scenario analysis: e.g., (COD, different regions, decarbonization assumptions, LDES duration archetype, LDES capital cost evolution, and Commercial Operation Date)
- Policies are then added to affect specific cash flow elements.

Below is a summary of the key model assumptions:

- **Energy arbitrage revenues** each year are the product of energy volumes discharged (as calculated based on utilization rates observed in the modeling performed in the 2021 analysis for Net-zero power[25]) and the marginal generating cost of a combined cycle gas turbine (e.g., operation and maintenance, fuel, and carbon costs), which is used as a proxy for the price of peak power.
- **Charging costs** were approximated as the product of energy volumes charged (driven by technology Roundtrip Efficiency and discharge energy volumes) and the levelized cost of energy (LCOE) for least-cost renewables (i.e., either wind or solar) in each modeled geography. The LCOE was blended to reflect an increasing share of negative or zero wholesale energy price from oversupply of renewable energy.
- **Revenues from ancillary services** were estimated as a function of project capacity allocated for such services and a fixed annual remuneration fee.
- **Policy and regulatory mechanisms** (e.g., grants, contracts for difference, etc.) were then layered on top either as a reduction in upfront cost (in the case of a grant) or a top-up / cap on the energy arbitrage earnings.

The basic physical principles of the model were extended to several different scenarios driven by the following dimensions:

- **Decarbonization scenarios:** affect carbon pricing, fuel costs, renewable LCOE, and LDES utilization, and by extension marginal generation and charging costs.
- **LDES asset archetype:** (8-24 hour or 24+ hour durations, as defined in Net-zero power, but modeled respectively as 12-hour and 36-hour systems), which impact utilization, charge / discharge energy volumes, and project costs.
- **LDES CAPEX cost decline scenarios:** (central vs. accelerated, as defined in Net-zero power) that affect upfront and ongoing costs.
- **Commercial Operation Date (COD):** affects which period of cash flows is considered as well as the upfront capital cost of the LDES asset.
- **Geographic region:** affects LDES utilization rates, carbon pricing, fuel costs, and renewable LCOEs.
- **Weighted Average Cost of Capital (WACC):** impacts NPV calculation and is assumed to vary between scenarios where long-term revenue support policies are or are not applied.

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[25] Modeling which the LDES Council expects to update in 2022 as part of its annual analytical report refresh.

# Illustrative business case example

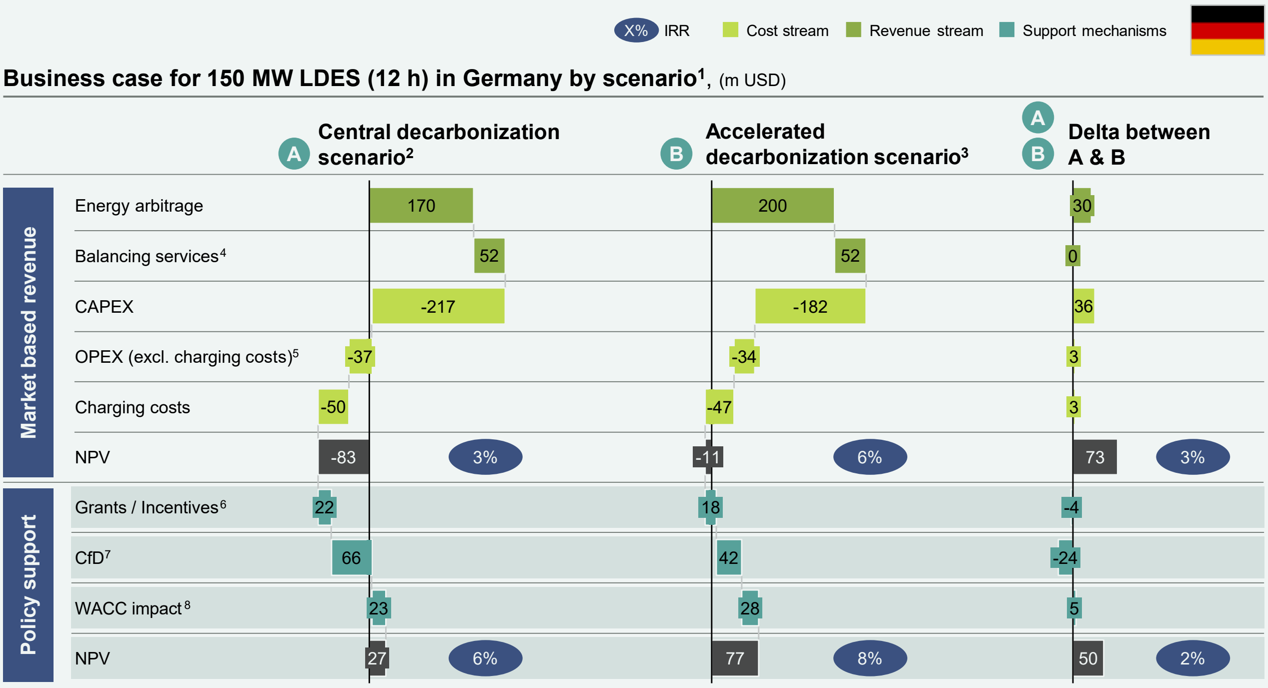
## Policy and regulatory tools have the potential to dramatically enhance early LDES customer and investor project viability.

**The baseline business case produces a negative NPV and weak IRR.** In the Central decarbonization scenario, a 150 MW, 12-hour system (1.8 GWh storage) operational in 2025 and operating for 35 years in the German power system produces negative NPV (USD ~(80)M) and weak IRR (~3%). This assessment is without policy support. (Please refer to Exhibit 12 on next page).

**More ambitious decarbonization and a faster cost decline improves the NPV and doubles the IRR.** With more aggressive decarbonization and LDES cost decline assumptions as would be expected with an acceleration in the German decarbonization agenda (i.e., moving from the Current Trajectory to Achieved Commitments), the NPV improves but remains negative (USD ~(10)M), with IRR (~6%) approaching assumed WACC (6%).

Exhibit 12

## Business case for 150 MW LDES (12 h) operational by 2025 in Germany



**Business case for 150 MW LDES (12 h) in Germany by scenario[1]**, (m USD)

1. Based on 12 h duration LDES with 150 MW of capacity deployed in 2025 with 30 years lifetime;
2. Assumes 2050 prices for $CO_2$ of ~170 USD/t, and for electricity of ~105 USD/MWh; average storage utilization of ~15%;
3. Assumes 2050 prices for $CO_2$ of ~210 USD/t, and for electricity of ~130 USD/MWh; average storage utilization of ~15% and accelerated rate of LDES CAPEX & OPEX decrease over time;
4. Assuming that 20% of LDES capacity would participate on balancing market, receiving a fixed payment of 140 USD/kW/year;
5. Opex includes all O&M costs excluding charging costs and transmission costs
6. Assuming grant of 10% of CAPEX;
7. Contract for difference assuming 15 years support period and strike price of 130 USD/MWh;
8. Assuming WACC decrease from 6% to 5% given risk reduction

**A combination of policy tools can turn the NPV positive in both scenarios.** In this illustrative example, a combination of grants[26] and a Contract for Difference for wholesale energy market (arbitrage) revenues[27] can be applied to generate a positive financial return (in the Current Trajectory scenario, total policy support is equivalent to USD ~90M over the course project lifetimes). An accelerated decarbonization agenda sees support costs reduced by ~30% as the underlying market fundamentals favor LDES through higher marginal generating and lower charging costs (as well as reduced upfront CAPEX, which in turn reduces the absolute magnitude of the grant funding applied).

**Further, the existence of long-term revenue support also reduces the cost of capital.** The application of the long-term revenue support contract (in this example, the CfD) is assumed to drive a reduction in WACC of 100 basis points[28] (i.e., 5% vs. 6% in baseline) associated with the reduction in project risk given the long-term offtake agreement. Across both decarbonization scenarios the reduction in WACC produces NPV uplift of USD ~25M.

---

[26] Assuming grant of 10% of CAPEX

[27] Contract for difference assuming 15 years support period and strike price of 130 USD/MWh

[28] The 100 bp reduction in WACC is likely conservative given the significant reduction in exposure to wholesale market volatility. Analysis by the IEA indicates that WACC's in 2019 of European utility-scale solar PV projects ranged from 2.4-4% for projects with revenues supported (i.e., feed-in-tariffs, contract for difference, long-term PPA, bilateral agreement) versus 5.9-8.8% for projects with full merchant risk – an average difference over 4%.

# LDES societal value creation potential

## Deploying LDES can unlock wider energy system benefits, as well as other societal dividends such as new employment opportunities and improved energy security.

**Using figures calculated in the LDES Council's 2021 Net-zero power report, an estimate for the net societal value creation was developed considering the cost of the policy support and comparing it to the network (i.e., transmission and distribution) and generation capacity savings.** Normalizing and annualizing the magnitude of the value created by LDES to 2040 for Germany on a per-MW capacity basis results in value creation of ~30,000 USD/MW-yr vs. illustrative support cost of ~20,000 USD/MW-yr in the German example. This net societal benefit waterfall is illustrated in Exhibit 13, which also juxtaposes an estimate of the per-MW cost of Germany's solar Feed-in-Tariffs versus the illustrative support provided to LDES.

**Full societal benefits are likely to be higher as impacts on the wider economy, energy security, and health are not included.** This value creation figure does not consider additional, knock-on benefits such as the contribution to jobs and GDP growth, the impact on energy security from a reduced reliance on imported fuels, or health benefits from reduced air pollution. On the potential value creation from employment, a recent study suggests that jobs in energy storage can reach 10 million globally by 2050[29]. Similar clean energy industries have provided and are expected to drive substantial job growth. For example, in the UK the offshore wind industry is alone expected to support 60,000 jobs by 2030.

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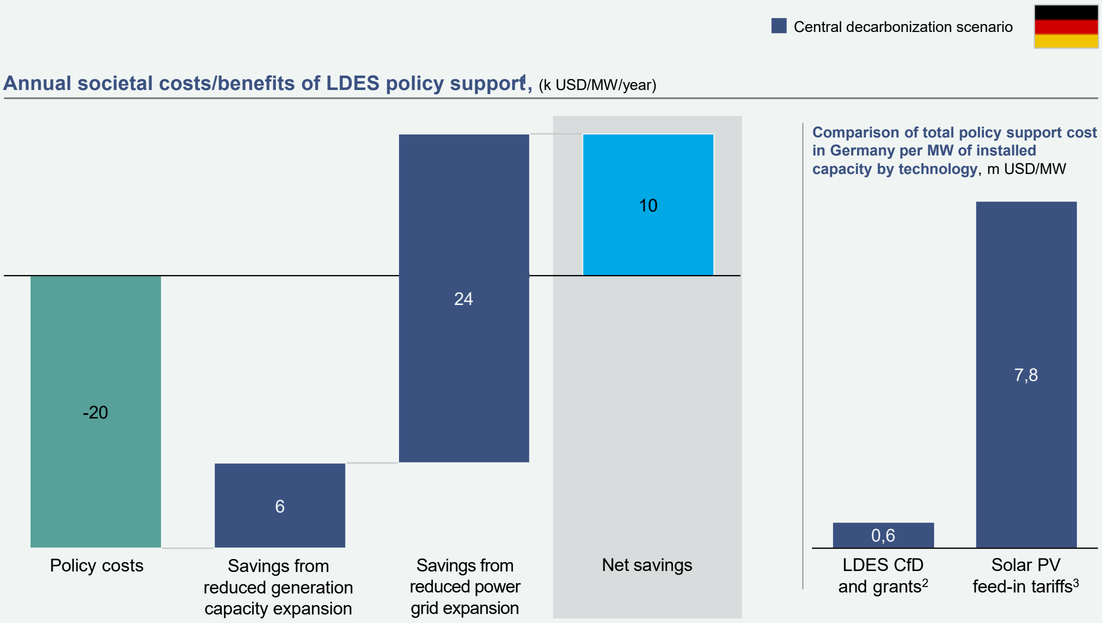
[29] Ram, Manish, Juan Carlos Osorio-Aravena, Arman Aghahosseini, Dmitrii Bogdanov, and Christian Breyer. "Job creation during a climate compliant global energy transition across the power, heat, transport, and desalination sectors by 2050." Energy 238 (2022): 121690.

Exhibit 13

### Benefits from LDES expected to exceed cost of policy support



1. Based on total policy support cost related to grant and a 15-years CfD contract for 150 MW 12 h LDES deployed in 2025. Calculation focuses on external effects and assumes that rest of CAPEX & OPEX is covered by market revenues. Social benefits reflect average annual potential of social benefits between 2025 – 2040 as external effects of LDES deployment and that as such LDES is not financially remunerated
2. Calculated by normalizing the lifetime policy support cost (USD 88m) by the plant capacity (150 MW)
3. Based on total estimated cost of feed-in tariffs (EUR ~150b or USD ~170b) over 20-year period for solar PV installations deployed between 2002 and 2016 (~22 GW)

# Gas price sensitivity and LDES as system hedge against fuel costs

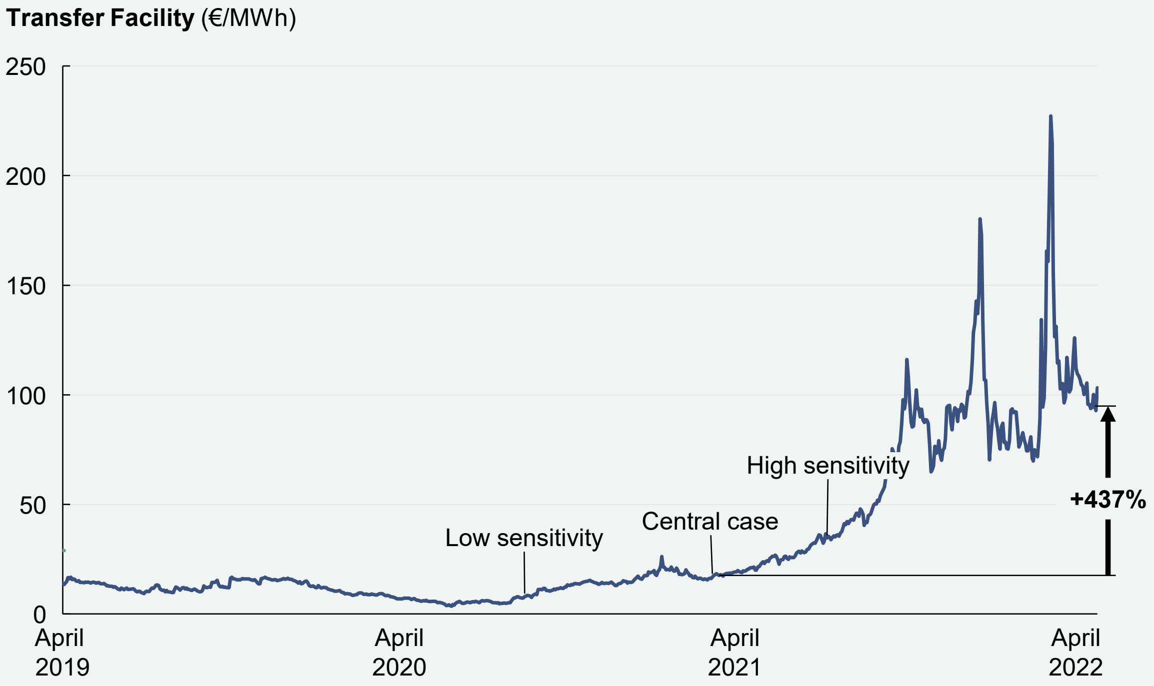
## Elevated natural gas prices as seen in the current environment increase peak capture prices in wholesale markets and would theoretically reduce the magnitude of policy compensation required.

**The business case of LDES is sensitive to gas prices.** Wholesale market spreads were estimated in the model using marginal generating costs for natural gas turbines, therefore, energy arbitrage revenues and business case NPV are sensitive to underlying fuel cost assumptions for natural gas.

**Gas prices have fluctuated between less than EUR 30/MWh (USD 32) and more than EUR 200/MWh (USD 211) in the last 12 months.** Exhibit 14 shows the changes in gas prices in Europe over the last three years and notes the price levels that are represented in the sensitivity analysis below. Gas prices have seen up to a tenfold change within the past year, as well as significant inter-month fluctuations, thereby dramatically impacting marginal wholesale generating costs (and potential competitiveness of LDES compared to conventional gas-fired flexibility). While current gas prices are much higher than under the high sensitivity used below, they have been below EUR 20/MWh in 2020 and 2021. Although gas prices may remain elevated in the near future, LDES developers cannot create business cases on current price spikes alone.

Exhibit 14

### European natural gas prices have been volatile and increasing in the last 12 months, affecting the business case for LDES



Dutch Title Transfer Facility (TTF) futures April 2019-April 2022, source: Investing.com

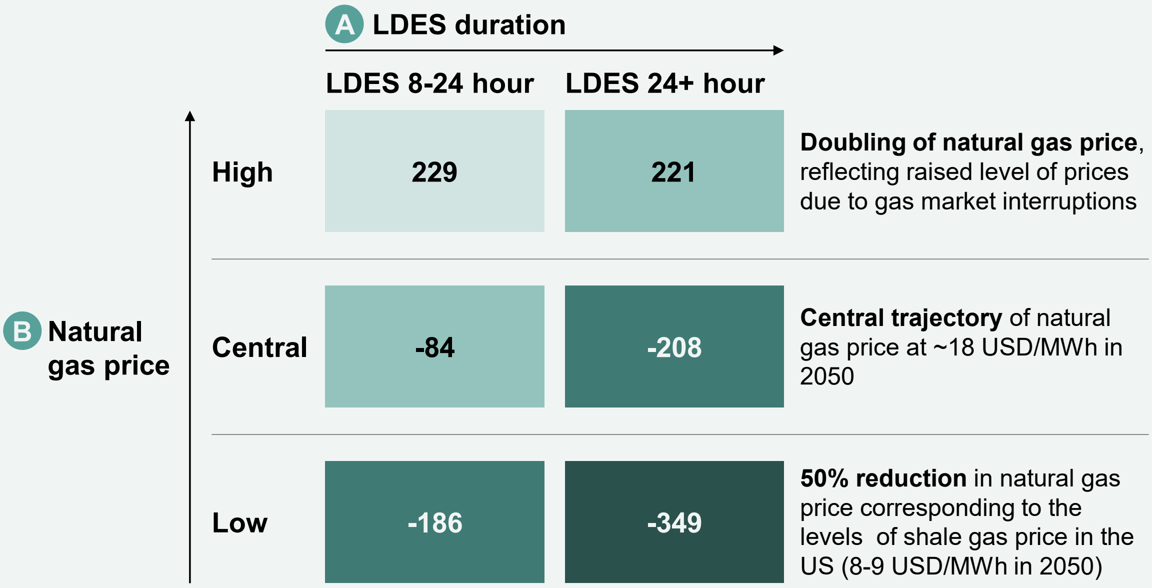
## Entering into long-term pricing support contracts for LDES can reduce exposure to volatile natural gas prices, as revenues above cap or CfD strike prices are returned to the funding pool, thereby also ensuring societal value of policy and regulatory support.

For the illustrative business case detailed above, NPV could range from (185)M to 230M USD depending on gas price assumptions. The sensitivity analysis has been performed in the central decarbonization scenario. The lower bound of this range assumes a 50% reduction in the gas price vs. base case (~18 USD/MWh), corresponding to cost levels of shale gas in the US (~8-9 USD/MWh), while the upper bound assumes doubling of natural gas prices reflective of a scenario with continued gas market disruptions (see summary in Exhibit 15 below).

The sensitivity of the arbitrage revenue stream emphasizes the importance of revenue mechanisms that focus on providing long-term offtake pricing / revenue certainty. While this revenue certainty is critical for ensuring viability of LDES projects, it also presents an advantage for policymakers in the form of a pricing hedge. Entering into long-term pricing support contracts for LDES can reduce exposure to volatile natural gas prices, as revenues above cap or CfD strike prices are returned to the funding pool, thereby also ensuring societal value of policy and regulatory support.

Exhibit 15

### Sensitivity of business case to gas prices for 150 MW LDES in Germany[1], (NPV, m USD)



Ⓐ **LDES duration**

Ⓑ **Natural gas price**

| | LDES 8-24 hour | LDES 24+ hour | |
|---|---|---|---|
| High | 229 | 221 | **Doubling of natural gas price**, reflecting raised level of prices due to gas market interruptions |
| Central | -84 | -208 | **Central trajectory** of natural gas price at ~18 USD/MWh in 2050 |
| Low | -186 | -349 | **50% reduction** in natural gas price corresponding to the levels of shale gas price in the US (8-9 USD/MWh in 2050) |

1. Based on 12 h duration LDES with 150 MW of capacity deployed in 2025 with 30 years lifetime, +2.0-2.5°C climate scenario assuming $CO_2$ price in 2050 reach ~170 USD/t, electricity price ~105 USD/MWh in the central scenario and average storage utilization of ~15%, assuming that apart of energy arbitrage, 20% of LDES capacity would participate on balancing market, receiving a fixed payment of 140 USD/kW/year

# 4.

# Pathways forward

Market archetypes

Planning the journey to net-zero power

**This last chapter addresses potential next steps for policymakers considering interventions to support LDES.** The first section introduces the concept of market archetype dimensions that can serve as a guide for the types of tools and the relative urgency of the need for policy support. The second section then discusses practical considerations to develop policy support for new clean energy technologies.

# Market archetypes

## Market archetypes can inform applicable policy mechanisms and the approach to planning and integrating low-carbon flexibility resources.

### Dimension #1:
### Power market unbundling

| | |
|---|---|
| **Description of dimension** | Fully unbundled power systems with separate ownership of generation, retail, transmission, distribution vs. vertical integration across power value chain. |
| **Implications for the power system** | Unbundling of power markets creates a competitive environment (particularly in generation or retail, whereas most network assets remain monopoly assets) wherein each entity is focused on the optimization of its own performance and hence maximization of its financial performance. As there is no opportunity for cross-business subsidization, each entity within the value chain must be a financially viable business. Differences in business profile and performance may also drive differences in cost of capital. However, just as different segments of the value chain cannot cross-subsidize each other in unbundled markets, they are also unable to capture any synergies that may exist between these businesses. A vertically-integrated power system on the other hand can justify investments in one business that generate savings or value in another. This nuance becomes particularly relevant because LDES assets can generate value for generation, trading, and networks businesses, but only vertically-integrated power utilities are able to realize this full potential and make investment cases on this basis. Transmission System Operators (TSOs) in unbundled markets, on the other hand, are not typically permitted to own and operate storage assets, and therefore cannot capture as many potential benefits from LDES deployment because they will be realized by other players in the power market. |
| **Implications for policy and regulatory actions** | For unbundled systems, revenue support mechanisms are critical for ensuring optimal power system operation. More specifically, these mechanisms are needed to ensure revenue streams are available for entities operating in a competitive landscape and to allow these entities to capture the value that is created for the system (the incentive structure should align the interests of the entity and the system). Of the revenue support mechanisms, the RAB is most directly relevant for vertically-integrated systems given the scope for these power companies to own storage assets. Where RAB mechanisms are potentially deployed for non-monopoly asset owners (i.e., an independent developer could agree a regulated rate of return on their capital investment), dual recovery via the RAB and market participation (e.g., market revenues could be shared with energy consumers) could also be considered. Long-term system planning tools play an important role across both unbundled and vertically-integrated systems as they set the overall direction respectively for the cluster of companies or single entity responsible for delivering the power system. |

## Dimension #2:
## Private ownership of the power sector

| | |
|---|---|
| **Description of dimension** | Private ownership of power sector companies or state ownership or partnership model that elevates the role of governmental or municipal stakeholders. Ownership can also vary within the power sector, e.g., private ownership of power generation and public ownership of transmission. Neither ownership structure is preferable over the other, but they come with different implications for the power system and policy and regulatory actions. |
| **Implications for the power system** | State-owned entities may have access to less expensive sources of capital, especially in jurisdictions that creditors deem to be broadly stable in terms of credit worthiness. Additionally, entities with government or municipal ownership may place greater emphasis on and solve for a broader set of societal mandates, such as faster pollution or emissions reductions, or the creation of employment opportunities for the local community. Entities that do not have government or municipal ownership may have elevated requirements on returns to shareholders given higher costs of capital but might be quicker to develop viable LDES projects irrespective of political priorities. |
| **Implications for policy and regulatory actions** | In state-owned power systems, governments will be responsible for ensuring that the power system adopts the right set of solutions and at the appropriate pace required to realize the energy agenda for broader society. These requirements naturally shape the strategies of both state- and private investor-owned enterprises, but in the case of state-owned entities there is an inextricable link and direct mandate for these entities to serve as the vehicle for change. The roles of long-term market signal policies and near-term direct support and enablement schemes become more pronounced in such environments. Power markets comprising principally private investor-owned entities may require greater support in the form of revenue support mechanisms that improve viability of assets and reduce investment risk. Notably, these markets will also need clarity in terms of long-term policy direction (as established by system planning) to make significant, long-lived infrastructure bets. |

## Dimension #3:
## Existing supply of low-carbon flexibility

| | |
|---|---|
| **Description of dimension** | Markets have varying levels of naturally-occurring (e.g., hydropower or biomass resources) or artificial (e.g., grid meshing and interconnectivity) forms of flexibility. In some regions, the natural difference in coincidence of peak output of solar and wind resources can also remove inherent variability and reduce need for incremental flexible capacity. |
| **Implications for the power system** | Barriers to adoption of new forms of flexibility are likely to be higher in systems with high levels of incumbent flexibility, given inherent competition with these resources (which benefit from established / mature and often low-cost positions) and the reduced urgency for additional sources of flexibility. |
| **Implications for policy and regulatory actions** | Markets with low levels of flexibility endowment will need to more aggressively pursue support mechanisms that secures additional flexibility resources, especially those with high levels of decarbonization ambition and/or existing renewable penetration (as described below). This implies a need for both direct support and enablement schemes and revenue support mechanisms to catalyze the creation of the sector, as well as long term system planning to create milestones commensurate with the overall energy policy. Markets with high levels of flexibility endowment would be under less pressure to catalyze the creation of a new sector. |

## Dimension #4: High vs. low energy transition ambition

| | |
|---|---|
| **Description of dimension** | Ambitions for energy transition vary by geography / jurisdiction (e.g., net-zero power system by 2035 vs. by 2050). The respective rationale for the energy transition may also vary, driven differentially by decarbonization, energy independence, or energy cost. |
| **Implications for the power system** | In markets with strong decarbonization ambition, there is an urgent need to phase out fossil fuels and support new forms of strong "energy transition" ambition flexibility that are consistent with a low-carbon future. Governments in these markets are more likely to be willing to invest resources, financial or otherwise, in the accelerated development of clean energy technologies. With lower or slower ambition, there is greater comfort with the status quo, also driven by a desire to avoid costs associated with the energy transition. These markets become solution-takers, adopting new solutions when these are sufficiently mature to present minimal or no additional cost vs. incumbent technologies, or when there is no alternative. |
| **Implications for policy and regulatory actions** | A market characterized by high decarbonization energy transition ambition will aim to quickly put in place a comprehensive and cohesive set of support mechanisms featuring the mix of different types of tools discussed in prior sections. Especially where there is heightened urgency, specific types of tools that offer greater ease of implementation, either because of their synergy with existing systems or due to their established track record, will be favored (for example over the design of novel mechanisms or those with more complex implementation requirements). This dimension more directly impacts the speed at which a support package is developed, as opposed to which specific policy types or tools are implemented. |

## Dimension #5: High vs. low variable renewable power penetration system

| | |
|---|---|
| **Description of dimension** | The amount of energy that is generated from variable renewable sources (e.g., wind, solar) differs greatly between regions, with some systems still predominantly fossil-fired while others routinely see greater than 50% instantaneous generation from renewables. |
| **Implications for the power system** | A system operating with greater quantities of variable renewable energy as a fraction of total production will necessarily require greater flexibility, with LDES being one potential technical solution. |
| **Implications for policy and regulatory actions** | Like dimension #4, a higher penetration of variable renewable energy can create urgency to explore new sources of flexibility and policy measures that can spur deployment of technologies like LDES. As such, this dimension too becomes a driver of the pace at which policy might be developed, as opposed to an indicator of specific policy types or tools. |

A few examples of market archetype assessments are included in Exhibits 16 and 17 on the next page.

Exhibit 16

## Example archetype analysis for German market

**Germany:** revenue mechanisms are a key enabler in unbundled system; urgency driven by high ambitions, RES penetration, and limited intrinsic flexibility

| Market archetype | Market archetype assessment Low High | Implications |
|---|---|---|
| **Power market unbundling** | ○ ○ ○ ○ ● | German power sector is fully unbundled with independent TSOs, therefore requiring strong signals for independent developers and in particular revenue mechanisms to enhance viability |
| **Private ownership of power sector** | ○ ○ ● ○ ○ | Mix of publicly and privately-owned companies suggests mixed ability to leverage lower borrowing costs; project return requirements for developers elevated, requiring revenue mechanisms |
| **Existing supply of low-carbon flexibility** | ○ ● ○ ○ ○ | Limited industrial demand response, lack of hydropower resources, and limitations in network capacity imply a long-term need for additional sources of flexibility to replace gas peakers |
| **Energy transition ambition** | ○ ○ ○ ○ ● | Germany recently announced a 2035 target for a net-zero power system, suggesting an urgent need for near-term support and enablement measures (e.g., grants) and strategic long-term planning |
| **Variable renewable penetration** | ○ ○ ○ ● ○ | Wind and solar accounted for approximately 30% of power generation in 2020, indicating an emerging need for flexibility and measures to support early deployments and industry scaling |

Source: IEA

Exhibit 17

## Example archetype analysis for California market

**California:** RAB natural investment pathway for vertically-integrated utilities, ambitious decarbonization targets and significant existing RES penetration implies need for clear long-term flexibility targets

| Market archetype | Market archetype assessment Low High | Implications |
|---|---|---|
| **Power market unbundling** | ○ ○ ● ○ ○ | Power utilities (e.g., Pacific Gas & Electric, Southern California Edison) permitted to own storage, making either RAB or procurement a viable mechanism for LDES assets (e.g., AB 2514 directs IOUs to procure storage) |
| **Private ownership of power sector** | ○ ○ ○ ● ○ | Majority of power companies in CAISO region are Investor-Owned Utilities (IOUs), implying lower centralization of risk and need for compensation mechanisms for independent asset developers |
| **Existing supply of low-carbon flexibility** | ○ ○ ● ○ ○ | As part of WECC[1], CAISO has access to hydro resources in the pacific northwest, but these are insufficient to replace fossil fuel capacity, implying a long-term need for additional flexibility |
| **Energy transition ambition** | ○ ○ ○ ○ ● | California is world-leading in terms of ambition for decarbonization, but unlocking net-zero carbon emissions by 2045 will require significant investment in power system flexibility |
| **Variable renewable penetration** | ○ ○ ○ ● ○ | In 2020, non-hydro renewables accounted for ~1/3 of generation, a share that is expected to grow and require additional flexible capacity especially as once-through cooling plants are retired |

1. Western Electric Coordinating Council

Source: California Energy Commission

# Planning the journey to net-zero power

**Given that it can take years to plan, build, shape, and evolve policy and regulatory frameworks, there is urgency to embark on this path today. Below are four high-level steps for consideration.**

**1.**

### Identifying needs through long-term planning

- Consider **unique characteristics** of the jurisdiction and relevant input assumptions.
- Run **energy system model** that studies both demand and generation and identifies the need for LDES capacity and duration.
- These assessments should also consider physical constraints i.e., infrastructure and permitting needs.
- Use **scenario analysis** to explore different pathways.

**2.**

### Understanding market for solutions and stakeholder requirements

- Conduct **inclusive stakeholder consultations** and calls for evidence to identify identify technology options for the local context, taking a system perspective and considering broader sustainability dimensions.
- Drive **interest in and dialogue around the opportunity** from potential technology providers and investors. Key stakeholders include the network and power utilities, energy traders and retailers, project developers, and commercial and industrial power users.

**3.**

### Developing and staging a suite of complementary policy tools

- Use the presented **toolbox as a starting point** when considering existing policies and rules to amend, or new policies or programs to create.
- Develop an **approach that combines** long-term system planning tools, revenue support mechanisms, and direct technology support and enablement schemes.

**4.**

### Reviewing and revising policy tools

- **Review policies regularly** as technology costs, infrastructure challenges and broader developments in the energy system will require changes to a policy suite to ensure its effectiveness to overcome barriers and value for public money.
- Pay particularly **close attention to revenue mechanisms** that target certain prices where lack of revision can cause lack of LDES deployment or inefficient use of public fund.

# 5. Conclusion

**The LDES Council's inaugural report in 2021 highlighted the role that LDES solutions can play in enabling net-zero power systems in support of a 1.5 degrees Celsius pathway set out in the Paris agreement.** That report also underscored the need for the right conditions to stimulate early investment in the LDES sector and accelerate commercial maturity of the asset class. Policymakers, regulators, and other stakeholders have an important role to play in creating the framework for these solutions to emerge and deliver on their promise.

**Policy and regulatory frameworks will necessitate combining different types of instruments to deliver long-term signals, remunerate assets for system services provided, and unlock opportunities for participation.** In the short term, emphasis on improving viability of initial projects will be key, and there is no shortage of potential policy and regulatory tools that can be deployed to that end. Additionally, most of these options have been successfully implemented to advance other clean energy technologies like solar or offshore wind.

**Looking ahead, there will be a variety of paths to net-zero power systems, shaped by unique starting points across the globe.** But what is universally clear is that developing supportive frameworks such as the ones described above takes time and time is of essence to scale manufacturing capacity and mobilize supply chains of nascent industrial sectors.

**The clock is ticking – achieving net-zero power systems in the early 2030s is critical to meeting the pathways established by the Paris Agreement and analyzed in the IPCC's recent Sixth Assessment Report.** Recent geopolitical events have placed acute emphasis on the decarbonization energy transition as a means of tackling both climate change and energy security. Regulatory and policy action plans must be developed and implemented today to equip society with solutions like LDES to meet this dual imperative.

**Policymakers and regulators have a range of tested tools at their disposal and their actions can make a difference today if they adapt them to support LDES projects and technologies.** The assessment presented above indicates that there exist many suitable and effective measures that have successful precedents in accelerating other clean energy technologies. These mechanisms can be deployed today and start laying the groundwork for secure, net-zero power systems in the 2030s.

# Appendix

## Reference examples of policy and regulatory support

### Example support mechanisms for energy storage: Germany, Spain, UK

| Policy types | Germany | Spain | UK |
|---|---|---|---|
| **Long-term market signals** | **Emissions target:** 65% overall $CO_2$ reduction by 2030<br>**Carbon pricing:** EU ETS (~80 EUR/ton)<br>**Renewables target:** Ambitious RES build-out targets with the goal of reaching 80% renewable share in the electricity mix by 2030, and net-zero power system by 2035 | **Energy Storage Strategy**: 20 GW of storage by 2030, 30 GW by 2050<br>**Carbon pricing:** EU ETS (~80 EUR/ton)<br>**74%** of renewable generation by 2030 and **42%** of final energy use | **Emissions target:** 78% carbon emission reduction by 2035<br>**Carbon pricing:** National carbon pricing (~80 GPB/ton)<br>**Renewables target:** Offshore wind target at 40 GW by 2030, coal-free power system by 2024, 100% electricity decarbonization by 2035 |
| **Revenue mechanisms** | **Grid services[1]:** frequency control and reserve, voltage stabilization, reactive power, short circuit current, network congestion management, and restoration | **Capacity market**: new "pay-as-bid" with 5-year contract to new, clean capacity under development<br>**Grid services[1]:** ancillary services (excluding multi-year grid services contracts), restoration and voltage support remuneration under evaluation | **Capacity market**: ~30-35 GBP/kW-y with long-term contacts<br>**Balancing market**: close to real-time balancing<br>**Hourly EACs**: hourly RES certificates being piloted by Elexon as of end of Apr. '22<br>**Grid services[1]:** Stability Pathfinder, Obligatory Reactive Power Service (ORPS), Dynamic Containment, restoration, Fast Frequency Response (FFR), Short Term Operating Reserve (STOR) |
| **Direct technology support and enabling measures** | **Grid charge exemption:** new storage assets are exempted from grid fees during first 20 years of operation, but are not permitted to charge during times of peak load | **Recovery, Transformation, and Resilience Plan**: €684M for storage and smart grids<br>**System charge exemptions**: storage assets are exempt from several grid charges | **Ten Point Plan**: £100M in funding support for storage<br>**BEIS**: £20M for large-scale storage, £9M on storage cost reduction<br>**UK Research Institute**: £330m<br>**Single grid tariff charge**: Storage assets no longer required to pay grid tariffs upon both charging and discharging |

## Example support mechanisms for energy storage: NYISO, CAISO, and PJM (US)

| Policy types | NYISO | California | PJM |
|---|---|---|---|
| **Long-term market signals** | **Emissions target:** 85% carbon emission reduction by 2050<br>**Renewables target:** 100% carbon-free electricity by 2040<br>**Storage capacity targets:** New York with a target of 6,000 MW of storage by 2030; additionally the six IOUs have a target of 350 MW of bulk-sited storage each by 2030 | **AB2514:** procurement targets set for IOUs for 1,500 MW of additional storage by 2024<br>**LDES target:** 1 GW of LDES (8+ hours) by 2026<br>**Carbon pricing** (~30 USD/ton)**,** 52% RPS by 2027, 100% by 2045 + SB423 on firm capacity | **Renewables target:** i.e. Maryland 50% by 2030; New Jersey 50% by 2030, 100% by 2050; Virginia 100% by 2050 (IOUs), Delaware 25% by 2026<br>**Energy storage targets:** New Jersey with 2,000 MW by 2030; Virginia with 3,100 MW by 2035 |
| **Revenue mechanisms** | **Resource Adequacy:** Utilities are required to maintain an adequate capacity to meet peak load demand via Installed Capacity Market (ICAP) with auctions (spot, monthly, 6-months)<br>**Grid services[1]:** Regulation and Operating Reserve, Energy Imbalance, Voltage Control and Restoration. | **Nodal LMPs:** enhanced energy arbitrage opportunities<br>**Resource Adequacy:** peak capacity 3-year contracts; CPUC requires three RA filings annually for system, local and flexible Resource Adequacy for Load-Serving Entities<br>**Grid services[1]:** up/down regulation, (non-spinning reserve, flex ramping products | **CM:** capacity procured three years in advance via competitive auctions varied by location and access to the transmission grid<br>**Nodal LMPs:** enhanced energy arbitrage opportunities<br>**Grid services[1]:** non-/synchronized reserve market, day-ahead scheduling reserve market and the regulation market |
| **Direct technology support and enabling measures** | **NY Green Bank:** $200 Million available to storage project developers<br>**NYSERDA:** $405 million through its Market Acceleration Bridge Incentive Program<br>**Bulk Energy Storage Incentive Program:** Storage under 20 MW to receive incentives ($100/kWh in 2020)<br>**Sandbox:** pilot microgrid program in Brooklyn<br>**DOE Energy Storage Grand Challenge:** reduce LDES cost by 90% by 2030 (10+ hours) | **State funding:** $380M in 2022-23 budget for LDES as part of the State's $2B Clean Energy Investment Program<br>**DOE Energy Storage Grand Challenge:** reduce LDES cost by 90% by 2030 (10+ hours) | **Smart Grid Investment Matching Program:** $3 Billion for improving grid flexibility & energy storage<br>**Maryland Energy Storage Pilot Program:** 5-year energy storage pilot programs to monitor net customer benefits<br>**DOE Energy Storage Grand Challenge:** reduce LDES cost by 90% by 2030 (10+ hours) |

1. In most cases grid services are not exclusively designed to support storage assets, but are accessible revenue streams

Source: NYISO, NY 2022 State of the State Address, CPUC, California Budget Summary 2022-2023

# Example support mechanisms for energy storage: Australia, Chile, India

| Policy types | Australia | Chile | India |
|---|---|---|---|
| **Long-term market signals** | **Emissions target:** Net-zero economy by 2050<br>**Renewables target:** 100% renewable power system by 2030<br>**Storage capacity target:** State level targets e.g., New South Wales 2 GW long duration energy storage target by 2030 | **Renewables target: 8**0% by 2030; 100% by 2050; 45% renewable share for all new capacity between 2014 and 2025;<br>**Carbon pricing:** ~5 USD/ton<br>**Storage capacity target:** JV with AES to deploy 300 MW of storage by 2023 | **Emissions target:** Net-zero economy by 2070 and emissions intensity reduction of 33-35% by 2030 from 2005 levels<br>**Renewables target:** 175 GW by 2022 and 500 GW by 2030<br>**Storage tenders:** four 1,000 MWh tenders across each of India's Regional Load Dispatch Centres |
| **Revenue mechanisms** | **Western Australia Reserve Capacity Mechanism (RCM):** Capacity market in Western Australia with benchmark price of AUD 151-500 per MW-year with locked 5-year contracts<br>**Grid services[1]:** Frequency Control Ancillary Services (FCAS), Network Support and Control Ancillary Services (NSCAS), System Restart Ancillary Services (SRAS), System Integrity Protection Scheme (SIPS) | **Capacity market**: availability payments for firm generating capacity<br>**Grid services[1]:** frequency control, voltage control, contingency control and recovery<br>**Locational marginal prices** : over 2,000 nodes, settled hourly | **"Round-the-clock" PPAs:** Power Purchase Agreements (PPAs) by the Solar Energy Corporation of India (SECI) for firmed renewable energy (firming can be achieved with storage, thermal sources, or conventional hydropower)<br>**Grid services[1]:** draft regulations allowing participation in frequency control and reserve services |
| **Direct technology support and enabling measures** | **ARENA:** partial project cost support for energy storage, with reporting requirements<br>**Clean Energy Finance Corporation:** AUD 6.4B for projects supporting low emission economy | **Development bank financing:** Direct subsidies into pre-feasibility and pre-investment projects for low carbon projects (capped at 160,000 USD) | **Targeted tenders:** Government announced initial 4GWh tender for energy storage |

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1. In most cases grid services are not exclusively designed to support storage assets, but are accessible revenue streams

Source: United Nations, Institute for Energy Economics and Financial Analysis, Indian Ministry of Power and New and Renewable Energy

## Assessments of individual mechanisms

### Assessment: Carbon pricing and greenhouse gas reduction targets

🟥 Weak
🟨 Mixed
🟩 Fairly strong
■ Very strong

| Criteria | Indicator | Assessment | Rationale |
|---|---|---|---|
| **Viability enhancement** Ability of tool to enhance business case for customers and investors | ⓐ Enhancement of returns | 🟩 | Carbon pricing measures increases the market bid prices required by these marginal generators (which typically use fossil fuels), and therefore can also increase the spread between off-peak and peak electricity market prices that LDES assets can capture. |
| | ⓑ Reduction of project risk (spread on returns) | 🟨 | Carbon pricing generally does not address volatility of project revenues since underlying carbon prices remain variable in most carbon markets. |
| **Ease of implementation** Relative effort and complexity of deploying tool | ⓒ Relative effort / complexity of integration | 🟨 | Carbon pricing in the form of a carbon tax on fossil fuels can be implemented with relative ease, e.g., on top of existing fuel taxation. Emissions trading can be more complex to implement, requiring more infrastructure and market oversight. |
| | ⓓ Track record and industry precedent | ■ | Carbon pricing is a widely popular tool supporting decarbonization, in the form of taxes (e.g., Chile) or trade-able certificates (e.g., EU). |
| **Long-term effectiveness** Flexibility of tools to deliver long-term, cost-effective sustained impact | ⓔ Adaptability as technology matures | 🟩 | Carbon pricing is a flexible tool that, depending on the solution, could automatically adapt to changing needs of the energy environment in a given country (EU ETS systems with a market that is setting the price for $CO_2$) or require government adjustments to regulation (level of carbon tax). |
| | ⓕ Cost-effectiveness | 🟩 | Carbon pricing mechanism accounts for external effects of carbon emissions and hence can support maximization of total socio-economic benefits, but in practice many countries implement lower than optimal prices due to political considerations. |
| | ⓖ Ability to accelerate decarbonization agenda | ■ | Carbon pricing directly fosters decarbonization. |

# Assessment: Grid planning

🟥 Weak
🟨 Mixed
🟩 Fairly strong
🟢 Very strong

| Criteria | Indicator | Assessment | Rationale |
|---|---|---|---|
| **Viability enhancement** Ability of tool to enhance business case for customers and investors | ⓐ Enhancement of returns | n/a | Grid planning does not directly impact LDES returns. |
| | ⓑ Reduction of project risk (spread on returns) | n/a | Grid planning does not directly reduce risk for LDES investments. |
| **Ease of implementation** Relative effort and complexity of deploying tool | ⓒ Relative effort / complexity of integration | 🟩 | Grid planning is a standard procedure that is at the heart of the power system development process. However, it requires robust technical knowledge and modelling capabilities. |
| | ⓓ Track record and industry precedent | 🟢 | Standard procedure performed by all transmission/distribution system operators. |
| **Long-term effectiveness** Flexibility of tools to deliver long-term, cost-effective sustained impact | ⓔ Adaptability as technology matures | 🟢 | Grid planning process could easily include assessment of a wide set of additional assets as alternatives to classical grid expansion. |
| | ⓕ Cost-effectiveness | 🟢 | Ultimate goal for grid planning is to optimize power system performance at acceptable cost level and hence maximize overall social welfare. |
| | ⓖ Ability to accelerate decarbonization agenda | 🟢 | Grid optimization can support deployment of renewables and other low carbon technologies. |

## Assessment: Phase-out of fossil fuel subsidies

🟥 Weak
🟨 Mixed
🟩 Fairly strong
■ Very strong

| Criteria | Indicator | Assessment | Rationale |
|---|---|---|---|
| **Viability enhancement** Ability of tool to enhance business case for customers and investors | ⓐ Enhancement of returns | 🟩 | Removal of fossil fuel subsidies creates a level playing field for all technologies and similarly to carbon pricing, increases the LCOE for fossil fuels and as such potential spreads on the market. |
| | ⓑ Reduction of project risk (spread on returns) | n/a | Tool does not impact risk reduction for LDES. |
| **Ease of implementation** Relative effort and complexity of deploying tool | ⓒ Relative effort / complexity of integration | 🟩 | Removal of fossil fuel subsidies is administratively simple but removal of subsidies in general can be politically difficult. |
| | ⓓ Track record and industry precedent | ■ | Tool with a good track record, i.e. energy policy in EU. |
| **Long-term effectiveness** Flexibility of tools to deliver long-term, cost-effective sustained impact | ⓔ Adaptability as technology matures | 🟩 | Relatively flexible tool, however requires coordination between multiple regulatory and administrative bodies to create a cohesive policy environment. |
| | ⓕ Cost-effectiveness | ■ | Although it would increase prices on energy market in the short-term, the tool supports social welfare improvement by reducing carbon-intensive generation and removing market distortions. |
| | ⓖ Ability to accelerate decarbonization agenda | ■ | Tool directly supports phase-out of fossil fuels, leveling playing field for low-carbon technologies. |

# Assessment: Procurement targets

🟥 Weak
🟨 Mixed
🟩 Fairly strong
🟢 Very strong

| Criteria | Indicator | Assessment | Rationale |
|---|---|---|---|
| **Viability enhancement**<br>Ability of tool to enhance business case for customers and investors | ⓐ Enhancement of returns | 🟨 | Procurement targets create stable long-term demand in specific customer segments, enhancing customer uptake and willingness-to-pay, and thereby also impacting project returns in a nascent market. |
| | ⓑ Reduction of project risk (spread on returns) | 🟩 | Project returns are somewhat derisked (i.e., there is some downside protection) due to creation of customer demand signals. |
| **Ease of implementation**<br>Relative effort and complexity of deploying tool | ⓒ Relative effort / complexity of integration | 🟨 | Tool requires designing dedicated procurement mechanisms for LDES asset classes and potentially adoption of relevant supporting regulation and cooperation between multiple government entities (i.e., who owns, who operates, who is the sponsor) that are involved in the process. |
| | ⓓ Track record and industry precedent | 🟢 | Procurement targets are widely used in other sectors. |
| **Long-term effectiveness**<br>Flexibility of tools to deliver long-term, cost-effective sustained impact | ⓔ Adaptability as technology matures | 🟢 | Flexible tool that could accommodate technology development and changing system needs. |
| | ⓕ Cost-effectiveness | 🟩 | Procurement targets if constructed properly support delivery of the most cost-effective solutions. However, developing procurement mechanisms in a cost-efficient manner can be challenging. |
| | ⓖ Ability to accelerate decarbonization agenda | 🟩 | Tool has potential to accelerate decarbonization if procurement process stipulates carbon impact requirements as part of conditions for eligibility. |

# Assessment: Renewable energy targets

🟥 Weak
🟨 Mixed
🟩 Fairly strong
■ Very strong

| Criteria | Indicator | Assessment | Rationale |
|---|---|---|---|
| **Viability enhancement** Ability of tool to enhance business case for customers and investors | ⓐ Enhancement of returns | 🟨 | Targets set for renewable uptake in the system may also spur demand for flexibility resources and therefore impact customer uptake and returns of LDES projects. |
| | ⓑ Reduction of project risk (spread on returns) | 🟨 | Project returns are somewhat derisked given clarity to industry of required renewables buildout, but impact on stability of LDES business cases is more muted. |
| **Ease of implementation** Relative effort and complexity of deploying tool | ⓒ Relative effort / complexity of integration | 🟨 | Effective renewable energy targets require robust system performance and development analysis and the creation of a cohesive regulatory environment that supports realization of targets, followed by a set of wide stakeholders consultations. Targets require a systemic approach to reporting and adaptation based on evolving needs. |
| | ⓓ Track record and industry precedent | ■ | Strong track record of renewables targets in multiple countries i.e. EU or California (Renewables Portfolio Standard). |
| **Long-term effectiveness** Flexibility of tools to deliver long-term, cost-effective sustained impact | ⓔ Adaptability as technology matures | 🟩 | Renewable energy targets are relatively flexible tools that, based on continuous power system development monitoring and performance analysis, could be easily adapted to evolving needs. However, any changes may be implemented with a certain delay, given inertia of the regulatory approval processes. |
| | ⓕ Cost-effectiveness | 🟩 | Renewable energy targets can be based on socio-economic studies that look for a global optimum that would minimize costs and maximize benefits, but countries also use different approaches that can lead to suboptimal targets. |
| | ⓖ Ability to accelerate decarbonization agenda | ■ | Additional renewable energy supply can unlock decarbonization across transport, building and industrial sectors. |

# Assessment: Storage capacity targets

🟥 Weak
🟨 Mixed
🟩 Fairly strong
■ Very strong

| Criteria | Indicator | Assessment | Rationale |
|---|---|---|---|
| **Viability enhancement** Ability of tool to enhance business case for customers and investors | ⓐ Enhancement of returns | 🟨 | By providing a long-term signal for required storage capacity (ideally of different storage durations), storage targets can mobilize the value chain and create demand for LDES, enhancing customer willingness-to-pay and thereby spurring an improvement on project returns. |
| | ⓑ Reduction of project risk (spread on returns) | 🟩 | Project returns are somewhat derisked (i.e., there is some downside protection) due to creation of customer demand signals. |
| **Ease of implementation** Relative effort and complexity of deploying tool | ⓒ Relative effort / complexity of integration | 🟩 | Storage capacity targets require robust system performance and development analysis and creation of cohesive regulatory environment supporting realisation of targets, followed by a set of wide stakeholders consultations. Additionally, capacity targets require a systemic approach to reporting and adaptation based on evolving needs. |
| | ⓓ Track record and industry precedent | 🟩 | Increasing number of jurisdictions set storage capacity targets, particularly in the US i.e. California, PJM, NYISO. |
| **Long-term effectiveness** Flexibility of tools to deliver long-term, cost-effective sustained impact | ⓔ Adaptability as technology matures | 🟩 | Storage capacity targets are relatively flexible tools that, based on continuous power system development monitoring and performance analysis, could be easily adapted to evolving needs. However, any changes may be implemented with a certain delay, given inertia of the regulatory approval processes. |
| | ⓕ Cost-effectiveness | 🟩 | Storage capacity targets can be based on socio-economic studies that look for a global optimum that would minimize costs and maximize benefits, but countries also use different approaches that can lead to suboptimal targets. |
| | ⓖ Ability to accelerate decarbonization agenda | 🟩 | By supporting deployment of storage capacities fostering system flexibility, targets accelerate decarbonization agenda. |

# Assessment: Cap & Floor

| | |
|---|---|
| 🟥 | Weak |
| 🟨 | Mixed |
| 🟩 | Fairly strong |
| ■ | Very strong |

| Criteria | Indicator | Assessment | Rationale |
|---|---|---|---|
| **Viability enhancement**<br>Ability of tool to enhance business case for customers and investors | ⓐ Enhancement of returns | ■ | Cap & floor mechanism provides a minimum energy capture price that would be necessary to cover all costs related to operation and financing. At the same time, revenue is curbed by the cap, which depending on the solution could be "soft" or "hard". |
| | ⓑ Reduction of project risk (spread on returns) | 🟩 | Cap & floor mechanism effectively reduces the risk of price extremes, however final revenue of LDES could vary depending on the price fluctuations within a range (cap – floor). Elimination of that risk is provided by CfD. |
| **Ease of implementation**<br>Relative effort and complexity of deploying tool | ⓒ Relative effort / complexity of integration | 🟩 | Cap & floor mechanism is a relatively easy instrument to implement, that would require creating a mechanism for price reporting. At the same time, setting of the level of cap & floor may require performing detailed analysis or be the outcome of a tender. This becomes particularly difficult when technology costs are expected to fall steeply. |
| | ⓓ Track record and industry precedent | ■ | Mechanism is well-known and currently used i.e. for interconnector transmission lines in the UK and commonly applied to provide price controls for monopoly assets. |
| **Long-term effectiveness**<br>Flexibility of tools to deliver long-term, cost-effective sustained impact | ⓔ Adaptability as technology matures | 🟩 | Cap & floor levels could be relatively easily adapted with decreasing costs of technology over time. However, the process requires robust analyses on justified cost levels as well as establishment of efficient cost process. |
| | ⓕ Cost-effectiveness | 🟩 | Tool supports optimization of LDES operations from the system perspective, as it enables asset operator to follow market price signals within the cap-floor range. At the same time, cap mechanism (especially hard cap) may distort incentive to operate in the face of critical system events. |
| | ⓖ Ability to accelerate decarbonization agenda | 🟩 | Cap & floor mechanism would provide targeted support to LDES asset class and hence directly support decarbonization but have only indirect impacts on other sectors and technology. |

# Assessment: Capacity market

🟥 Weak
🟨 Mixed
🟩 Fairly strong
🟢 Very strong

| Criteria | Indicator | Assessment | Rationale |
|---|---|---|---|
| **Viability enhancement**<br>Ability of tool to enhance business case for customers and investors | a Enhancement of returns | 🟨 | Classical capacity market is technology agnostic and provides additional remuneration for the availability of power capacity in the system for assets with the cheapest bids. Given higher costs for low emission technologies incl. LDES, classical capacity markets may not provide sufficient support. To mitigate this, a dedicated bucket for LDES/low carbon technologies may be required. |
| | b Reduction of project risk (spread on returns) | 🟩 | Once awarded, capacity market provides firm additional revenue throughout the length of a contract. However, such contract do not eliminate market risk related to energy arbitrage/balancing services offered by LDES. |
| **Ease of implementation**<br>Relative effort and complexity of deploying tool | c Relative effort / complexity of integration | 🟩 | Proper design of capacity markets, besides technical and IT organization, requires cohesive regulation/strategy for the entire power market that should eliminate any distortions that capacity market may bring (i.e. impact on price formation processes on energy floor). |
| | d Track record and industry precedent | 🟢 | Wide industry precedent of capacity mechanisms in Europe, i.e. capacity markets in the UK, Poland. |
| **Long-term effectiveness**<br>Flexibility of tools to deliver long-term, cost-effective sustained impact | e Adaptability as technology matures | 🟩 | Bidding process for capacity contracts enables accommodation of changes in technology costs. However, given the technology agnostic nature of a standard capacity market, direction of the support to technology with desired characteristics may require implementing additional asset buckets and/or rules for participants. |
| | f Cost-effectiveness | 🟩 | Capacity markets change model of electricity markets from “energy only markets” into “two commodities markets” and as such, if not constructed properly, may provide distortion to price signals on the energy market, decreasing social welfare. |
| | g Ability to accelerate decarbonization agenda | 🟨 | Classical capacity market design is not necessarily focused on deployment of low carbon technologies, but rather sufficient level of power capacities in the system. Additional emissions intensity standards could support decarbonization agenda for capacity market design. |

# Assessment: Contract for difference

🟥 Weak
🟨 Mixed
🟢 Fairly strong
🟩 Very strong

| Criteria | Indicator | Assessment | Rationale |
|---|---|---|---|
| **Viability enhancement** Ability of tool to enhance business case for customers and investors | a Enhancement of returns | 🟩 | CfD sets a certain level of capture price, which should enable LDES owner to recover all costs and provide a rate of return on invested capital sufficient to attract LDES investments. At the same time, CfD provides a cap on max revenue. |
| | b Reduction of project risk (spread on returns) | 🟩 | CfD effectively eliminates price risk for LDES as it sets firm level of capture price. |
| **Ease of implementation** Relative effort and complexity of deploying tool | c Relative effort / complexity of integration | 🟨 | CfD model requires building a reporting system for realized market prices for LDES asset. On top, CfD system requires organization of a bidding procedure for CfD contracts. |
| | d Track record and industry precedent | 🟩 | Model with a wide industry precedent i.e. CfD for electricity price for new investments in nuclear generation in UK. |
| **Long-term effectiveness** Flexibility of tools to deliver long-term, cost-effective sustained impact | e Adaptability as technology matures | 🟩 | Model is easily adaptable, with bidding process for capture price level secured in the contract that would follow changes in technology costs. |
| | f Cost-effectiveness | 🟢 | Classic CfD is designed to incentivize maximal output given its structure as a remuneration per MWh (volumetric energy sales), the tool may not support system-optimal dispatch unless there are established and robust flexibility / balancing markets. |
| | g Ability to accelerate decarbonization agenda | 🟢 | CfD provides direct support to LDES asset class and fosters renewables deployment. Further decarbonization can be facilitated by applying CfDs to other sectors. |

# Assessment: Hourly Energy Attribute Certificates

🟥 Weak
🟨 Mixed
🟩 Fairly strong
🟢 Very strong

| Criteria | Indicator | Assessment | Rationale |
|---|---|---|---|
| **Viability enhancement** Ability of tool to enhance business case for customers and investors | a Enhancement of returns | 🟩 | The ability for an LDES project developer to monetize hourly EACs would offer a supplemental income stream to projects and thereby enhance project returns. |
| | b Reduction of project risk (spread on returns) | 🟨 | The underlying market value of an hourly EAC would be subject to market forces of supply and demand, introducing variability in the offtake price that could impact the spread on project returns. This variability could be mitigated by entering into long term offtake agreements for the EACs (similar to long-term Power Purchase Agreements). |
| **Ease of implementation** Relative effort and complexity of deploying tool | c Relative effort / complexity of integration | 🟩 | Hourly EAC schemes are in theory straightforward to implement, requiring metering of renewable generator output and assignment of a timestamp to each certificate produced. Establishing liquidity in hourly EAC spot and derivative products will however be more challenging, especially vis-à-vis liquidity of annual RECs. |
| | d Track record and industry precedent | 🟢 | Strong track record of the traditional Renewable Energy Credit (REC), which is well-known as a policy tool for driving the marketplace for traditional variable renewable generation. |
| **Long-term effectiveness** Flexibility of tools to deliver long-term, cost-effective sustained impact | e Adaptability as technology matures | 🟢 | The hourly EACs are inherently market-tradeable instruments and therefore will reprice dynamically based on supply and demand. As the technology cost of supplying an hourly EAC comes down, so can market prices due to increasing competitive pressure by parties able to capture the lower technology cost. |
| | f Cost-effectiveness | 🟢 | Hourly EACs do not require funding by governments on behalf of electric consumers. In the short term, consumption of hourly EACs may increase energy expenditures, but could also provide a hedge against rising costs associated with fossil fuel power production. |
| | g Ability to accelerate decarbonization agenda | 🟩 | Hourly EACs are driving toward greater supply of renewable energy in each hour and therefore support the decarbonization agenda. |

# Assessment: Long-term balancing services

🟥 Weak
🟨 Mixed
🟩 Fairly strong
■ Very strong

| Criteria | Indicator | Assessment | Rationale |
|---|---|---|---|
| **Viability enhancement** Ability of tool to enhance business case for customers and investors | ⓐ Enhancement of returns | 🟩 | Balancing services contracts provide an additional revenue stream for LDES that can dedicate full/portion of capacity to a range of ancillary services. However, given the competition with other asset classes (incl. fossil fuels) during the bidding process, potential for revenue uplift may be limited. |
| | ⓑ Reduction of project risk (spread on returns) | ■ | Structured as long-term contracts, asset owners would have a predictable revenue stream from the provision of grid services. |
| **Ease of implementation** Relative effort and complexity of deploying tool | ⓒ Relative effort / complexity of integration | 🟨 | Implementation of long-term balancing contracts, in particular if some degree of standardization applies, would potentially require comparing offering for a different set of bundled balancing services (i.e., Asset A offering only inertia, Asset B offering inertia & frequency regulation). |
| | ⓓ Track record and industry precedent | 🟩 | Balancing contract can be a standard instrument on the electricity market. However, some ancillary services that could be offered by LDES i.e., inertia provision are not yet remunerated on majority of power markets. |
| **Long-term effectiveness** Flexibility of tools to deliver long-term, cost-effective sustained impact | ⓔ Adaptability as technology matures | 🟩 | Although a certain level of standardization is desirable, long-term balancing contract is a relatively flexible model. Contracts concluded for every new asset could be adapted based on changing system needs and developing technology. |
| | ⓕ Cost-effectiveness | 🟩 | Long-term balancing contracts create substantial benefits for the system securing its operation, however in some locations limited supply of assets may create risk of market concentration. |
| | ⓖ Ability to accelerate decarbonization agenda | 🟨 | Primary goal of long-term balancing contracts is to provide sufficient level of power quality and overall security of supply. If constructed properly, such contacts could also provide dedicated support to low carbon technologies. |

## Assessment: Nodal or locational marginal pricing

🟥 Weak
🟨 Mixed
🟩 Fairly strong
■ Very strong

| Criteria | Indicator | Assessment | Rationale |
|---|---|---|---|
| **Viability enhancement** Ability of tool to enhance business case for customers and investors | a Enhancement of returns | 🟩 | Nodal systems are inherently technology-agnostic, but could support a potential uplift in returns for strategically-located LDES assets (e.g., within a congested electrical boundary, or with access to excess renewable generation) able to capture higher spreads available in a nodal system. |
| | b Reduction of project risk (spread on returns) | n/a | Nodal pricing does not impact long-term investment risks, given that any changes to network topology, generation portfolio, or consumption patterns would dynamically affect power prices. |
| **Ease of implementation** Relative effort and complexity of deploying tool | c Relative effort / complexity of integration | 🟥 | Implementation of nodal pricing is a very complex process from both legislative and IT perspectives, that amounts to a redesign of a country's entire electricity market. |
| | d Track record and industry precedent | ■ | Model is widely used for US electricity markets, i.e. California, PJM. |
| **Long-term effectiveness** Flexibility of tools to deliver long-term, cost-effective sustained impact | e Adaptability as technology matures | ■ | Once set, nodal pricing automatically reacts to the changes in the market environment, both from the perspective of generation/demand assets as well as network structure. |
| | f Cost-effectiveness | ■ | Nodal market provides global cost optimum, effectively eliminating the need for remedial actions (i.e., redispatching) performed by transmissions system operators to correct infeasible market outcomes, hence maximizes social welfare. |
| | g Ability to accelerate decarbonization agenda | 🟨 | By definition, primary goal of nodal markets is to minimize total cost of system operation (both generation and power transmission/distribution), which may not be in line with decarbonization. |

# Assessment: Regulated asset base

🟥 Weak
🟨 Mixed
🟩 Fairly strong
■ Very strong

| Criteria | Indicator | Assessment | Rationale |
|---|---|---|---|
| **Viability enhancement** Ability of tool to enhance business case for customers and investors | ⓐ Enhancement of returns | ■ | Regulated Asset Base model (RAB) secures recovery of all costs and provides a regulated rate of return on invested capital (allowed revenue typically at level of a few percent). |
| | ⓑ Reduction of project risk (spread on returns) | ■ | RAB eliminates market risk for LDES revenue, as revenue is defined upfront by the regulator in the contract. |
| **Ease of implementation** Relative effort and complexity of deploying tool | ⓒ Relative effort / complexity of integration | 🟨 | RAB model requires detailed reporting of total costs of LDES operation on annual basis per asset unit as well as maintaining cost transfer mechanism to market participants, usually in a form of tariffs. |
| | ⓓ Track record and industry precedent | ■ | Model is the classic regulatory structure for incentivizing asset development of transmission and distribution networks (e.g., European TSOs). |
| **Long-term effectiveness** Flexibility of tools to deliver long-term, cost-effective sustained impact | ⓔ Adaptability as technology matures | ■ | Model is easily adaptable, as the LDES revenue calculation is a continuous process that needs to be performed per each asset. |
| | ⓕ Cost-effectiveness | 🟩 | Regulator is responsible for maximizing socio-economic benefits, however secured level of revenue in the classic RAB design model may not incentivize optimal LDES performance. |
| | ⓖ Ability to accelerate decarbonization agenda | 🟩 | RAB provides a direct support to LDES asset class, fosters renewables deployment and further decarbonization. |

## Assessment: 24/7 Clean PPAs

🟥 Weak
🟨 Mixed
🟩 Fairly strong
■ Very strong

| Criteria | Indicator | Assessment | Rationale |
|---|---|---|---|
| **Viability enhancement** Ability of tool to enhance business case for customers and investors | a Enhancement of returns | ■ | 24/7 Clean PPA provides a certain offtake price awarded in a public tender or via private contracts to “hybrid” installations of renewables and flexibility (e.g., energy storage, demand response), that should enable LDES owner to recover all costs and provide attractive rate of return on invested capital. Certain offtake price eliminates ability to secure excess revenues available during critical events. |
| | b Reduction of project risk (spread on returns) | ■ | 24/7 Clean PPA secures sales volumes with a certain probability defined in the contract. Thus, investor risk is reduced to the risk related to asset operation and technology performance. |
| **Ease of implementation** Relative effort and complexity of deploying tool | c Relative effort / complexity of integration | 🟩 | In public procurement processes 24/7 Clean PPA contracts would be awarded between market participants therefore requiring market regulations facilitating such agreements. 24/7 Clean PPA contracts struck in private arrangements may be less complex. |
| | d Track record and industry precedent | ■ | Conventional PPA contracts can be a standard instrument on the electricity market for renewables energy procurement, widely used in the EU with a particular acceleration in recent years. |
| **Long-term effectiveness** Flexibility of tools to deliver long-term, cost-effective sustained impact | e Adaptability as technology matures | ■ | 24/7 Clean PPA contracts can be concluded per asset basis, and hence detailed parameters can follow technology & costs reduction advancements. |
| | f Cost-effectiveness | 🟩 | 24/7 Clean PPA instruments, which usually take the form of confidential individual contracts, optimize for benefits of individual parties, which may not always lead to the global optimum from the system perspective. |
| | g Ability to accelerate decarbonization agenda | 🟩 | 24/7 Clean PPA contracts support LDES deployment but have limited impacts on other sectors and technology. |

# Assessment: Grants

🟥 Weak
🟨 Mixed
🟩 Fairly strong
■ Very strong

| Criteria | Indicator | Assessment | Rationale |
|---|---|---|---|
| **Viability enhancement**<br>Ability of tool to enhance business case for customers and investors | ⓐ Enhancement of returns | 🟩 | Grants are a tool that could support business case of LDES i.e., in the form of a one-time payment or extra support. |
| | ⓑ Reduction of project risk (spread on returns) | 🟨 | Grants improve the financial case of LDES, decreasing the gap to breakeven; however they do not reduce risks related to market driven revenues. |
| **Ease of implementation**<br>Relative effort and complexity of deploying tool | ⓒ Relative effort / complexity of integration | 🟩 | Implementation of grants requires creation of a system capable of assessing and awarding support to the best LDES projects/defined classes of LDES technologies. |
| | ⓓ Track record and industry precedent | ■ | The most popular tool to support uptake of new technologies in the power sector, i.e. support for distributed renewables in EU. |
| **Long-term effectiveness**<br>Flexibility of tools to deliver long-term, cost-effective sustained impact | ⓔ Adaptability as technology matures | 🟩 | Relatively adaptable tool as sources of capital can adjust financial support parameters depending on the stage of technology and market development. |
| | ⓕ Cost-effectiveness | 🟩 | Financial support carries potentially significant costs in the short to medium term, enabling development and cost reductions of LDES in early days. Real social benefits typically occur in the longer-term. |
| | ⓖ Ability to accelerate decarbonization agenda | 🟩 | Tool fosters decarbonization agenda with effects depending on available budget but has only indirect impacts on other sectors and technology. |

## Assessment: Sandboxes

🟥 Weak
🟨 Mixed
🟩 Fairly strong
🟢 Very strong

| Criteria | Indicator | Assessment | Rationale |
|---|---|---|---|
| **Viability enhancement** Ability of tool to enhance business case for customers and investors | ⓐ Enhancement of returns | n/a | Sandbox does not structurally support LDES returns. |
| | ⓑ Reduction of project risk (spread on returns) | n/a | Sandbox does not impact LDES financial risk. |
| **Ease of implementation** Relative effort and complexity of deploying tool | ⓒ Relative effort / complexity of integration | 🟢 | Sandbox is a relatively straightforward tool, implementation of which requires analysis of the current regulatory and market environment followed by relaxation and/or exemption from some of the rules. |
| | ⓓ Track record and industry precedent | 🟩 | Sandboxes are a common tool supporting uptake of new technologies across wide selection of industries, i.e. fintech sandboxes in the UK, Singapore. |
| **Long-term effectiveness** Flexibility of tools to deliver long-term, cost-effective sustained impact | ⓔ Adaptability as technology matures | 🟢 | Flexible tool which could be easily adapted based on the feedback from market participants and evaluation of changing technology and trends in the power market. |
| | ⓕ Cost-effectiveness | 🟩 | Sandboxes support emerging technologies at commercial, but relatively small-scale. While benefits might not be immediately tangible, they can unlock more substantial deployment and costs reductions. |
| | ⓖ Ability to accelerate decarbonization agenda | 🟨 | Similar to socio-economic benefits: although sandboxes could support growth of low carbon technologies, their relatively small-scale limits impact on effective decarbonization. |

# Assessment: Targeted tenders

🟥 Weak
🟨 Mixed
🟩 Fairly strong
■ Very strong

| Criteria | Indicator | Assessment | Rationale |
|---|---|---|---|
| **Viability enhancement** Ability of tool to enhance business case for customers and investors | a Enhancement of returns | 🟩 | Targeted tenders focus on a set of technologies that satisfy specific technical and functional requirements, excluding from competition non-compliant assets that usually have lower costs. If procurement happens via traditional auction, this possibly could enable LDES to achieve higher revenue. |
| | b Reduction of project risk (spread on returns) | ■ | Tender in which government or other end-consumer entity procures LDES, gives a certain price and hence significantly limits risks. |
| **Ease of implementation** Relative effort and complexity of deploying tool | c Relative effort / complexity of integration | 🟨 | Targeted tender requires good understanding of the optimal technology mix given local feasibility, power market structure and cost development and at the same time creation of tender mechanisms with rules that are wide enough to accommodate desired functional characteristics without limiting technology scope. Moreover, if the procuring party is a government entity, this requires defining who is the owner and what is the model for asset operation. |
| | d Track record and industry precedent | 🟩 | Targeted tender a well-known tool, in particular in construction industry, enabling procurement of asset with special characteristics while remaining technology-agnostic. |
| **Long-term effectiveness** Flexibility of tools to deliver long-term, cost-effective sustained impact | e Adaptability as technology matures | ■ | Targeted tender is easy and relatively fast to adapt by adjusting tender requirements. However, before setting the rules it is necessary to monitor available technologies and their evolution. |
| | f Cost-effectiveness | 🟩 | Targeted tenders are not necessarily a systemic solution optimizing overall long-term social welfare, but a tool of targeted short-term support for nascent technologies. |
| | g Ability to accelerate decarbonization agenda | 🟩 | A series of tenders selecting carbon neutral technologies can support broader decarbonization within the scope of the tenders. |

# Assessment: Investment de-risk mechanisms

🟥 Weak
🟨 Mixed
🟩 Fairly strong
■ Very strong

| Criteria | Indicator | Assessment | Rationale |
|---|---|---|---|
| **Viability enhancement** Ability of tool to enhance business case for customers and investors | a Enhancement of returns | 🟩 | By offering blended finance (incl. public and/or public-private) the tool lowers investment risk to private investors by bringing in a public investment partner, which in turn reduces project cost of capital. |
| | b Reduction of project risk (spread on returns) | 🟩 | |
| **Ease of implementation** Relative effort and complexity of deploying tool | c Relative effort / complexity of integration | ■ | Integrating de-risk mechanisms into the market is requires relatively little effort, encompassing creation of investment instruments and delivery mechanisms, project assessment and program budget management. |
| | d Track record and industry precedent | ■ | Public-private financing has wide industry precedent, in particular in the area of sustainable investing and/or public services delivery. |
| **Long-term effectiveness** Flexibility of tools to deliver long-term, cost-effective sustained impact | e Adaptability as technology matures | ■ | Easily adaptable tool that could be adjusted to follow recent technology development and changes in the power market. |
| | f Cost-effectiveness | 🟩 | Tool can blend risks between private and public player for technologies that provide societal value. |
| | g Ability to accelerate decarbonization agenda | 🟩 | Tool facilitates scaling-up of LDES deployment and hence fosters decarbonization of electricity systems but has only indirect impacts on other sectors and technologies. |

# Assessment: Market rules

🟥 Weak
🟨 Mixed
🟩 Fairly strong
🟢 Very strong

| Criteria | Indicator | Assessment | Rationale |
|---|---|---|---|
| **Viability enhancement** Ability of tool to enhance business case for customers and investors | ⓐ Enhancement of returns | 🟩 | Establishment of market rules creates a level playing field for LDES, providing access to existing markets or creating new trading floors/services that support LDES monetization, but effect on revenues is indirect only. |
| | ⓑ Reduction of project risk (spread on returns) | 🟨 | In principle, market rules do not eliminate LDES investment risk but rather ease the burden of some requirements or provide access to markets. |
| **Ease of implementation** Relative effort and complexity of deploying tool | ⓒ Relative effort / complexity of integration | 🟥 | Creation of effective market rules is a complicated process that is time consuming and requires coordination with multiple bodies including consultations with market participants and in some cases amending legislation. |
| | ⓓ Track record and industry precedent | 🟢 | Excellent track record with dedicated market regulations supporting growth of renewables and hydrogen e.g., in EU. |
| **Long-term effectiveness** Flexibility of tools to deliver long-term, cost-effective sustained impact | ⓔ Adaptability as technology matures | 🟩 | Core elements of market rules are usually universal with some elements specific to technology and as such should be constantly revised with changing market conditions and technology improvements. At the same time, regulation adjustments take time as they depend on legislative procedures. |
| | ⓕ Cost-effectiveness | 🟩 | Generally, market rules are created to maximize long-term socio-economic benefits, however in the short-term they may increase the costs for the system. |
| | ⓖ Ability to accelerate decarbonization agenda | 🟩 | Market rules enable LDES deployment but have only indirect impacts on other sectors and technologies. |

## Assessment: Technology standards

🟥 Weak
🟨 Mixed
🟩 Fairly strong
■ Very strong

| Criteria | Indicator | Assessment | Rationale |
|---|---|---|---|
| **Viability enhancement** Ability of tool to enhance business case for customers and investors | a Enhancement of returns | n/a | Technology standards do not improve LDES business case per se. |
| | b Reduction of project risk (spread on returns) | n/a | Technology standards do not reduce LDES investment risks. |
| **Ease of implementation** Relative effort and complexity of deploying tool | c Relative effort / complexity of integration | 🟨 | Technology standards require performing robust analyses of the system requirements (which is usually associated with energy system modelling) as well as good understanding of currently available technology and projections of potential for further development. |
| | d Track record and industry precedent | ■ | Technology standards are usually developed in parallel to regulation as inevitable element of comprehensive regulation. Examples include EU technology requirements for power generators, requirements for ancillary services providers. |
| **Long-term effectiveness** Flexibility of tools to deliver long-term, cost-effective sustained impact | e Adaptability as technology matures | ■ | Technology standards are adaptive and should always follow recent technology developments. |
| | f Cost-effectiveness | 🟩 | Primary goal of technology standards is to impose minimum parameters that would be required to satisfy system needs and policy goals, hence they support creation of overall socio-economic benefits. |
| | g Ability to accelerate decarbonization agenda | 🟨 | Technology standards may support a path towards carbon neutrality, however they do not necessarily accelerate the process. |

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