Markets designs for low-carbon, low-cost electricity systems

IRENA - Innovation week

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Key Messages

The economics or electricity markets are changing due to new technology and carbon constraints

We need to develop and incentivize different sources of flexibility – batteries, demand management, flexible generation – while keeping finance costs low, to benefit from these new economics

Current approaches to electricity market design solve only a part of the problem, while creating new problems

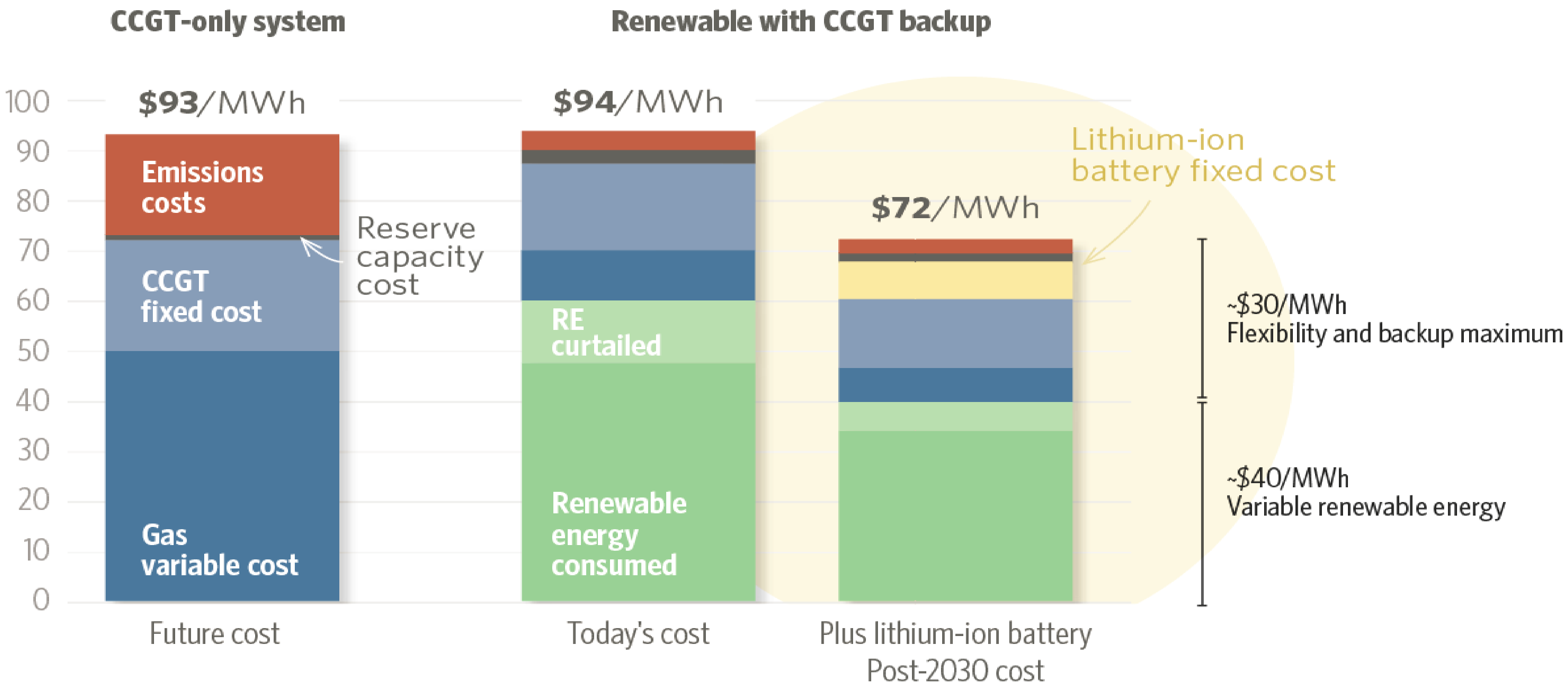
A low cost and effective way forward would combine parts of different electricity market concepts and tailor them to the technical and financial characteristics of low carbon and flexible technology

With the right market design, by 2030 a new electricity system based almost entirely on variable renewable energy could be cheaper than a gas based system

Changing Economics

Total cost of generation from renewables and CCGT-based systems including flexibility (with a carbon price)

Power generation and balancing cost
$/MWh, including $50/tonne CO_2 carbon value



The system needs to meet many flexibility requirements that grow with increased shares of low-carbon power

Power systems require multiple types of flexibility to manage variability and uncertainty

Increase in flexibility needed with growth of low-carbon power

		Type of flexibility	**Renewables-based**	**Nuclear**	**Fossil fuels with CCS**
Real-time operations	<1 min 5 min	**Spinning and load-following**	**Low to moderate** Modest increases in forecast error with more variable generation	**Low** Low demand forecast errors	**Low** Low demand forecast errors
	5 min 15 min	**Short-term reserve**			
Scheduling and forecasting	Hour	**Ramping**	**Moderate to high** Daily patterns (eg, sunset) lead to substantial ramping needs	**Low to moderate** Baseload nuclear has limited ramping capability	**Low to moderate** Baseload fossil fuels with CCS has limited ramping capability
	Day	**Intraday / daily balancing**	**Moderate to high** Misalignment between generation and load drives hourly over/under-production	**Moderate to high** Constant supply and variable demand creates need for daily energy shift	**Moderate** Following demand lowers capacity factor, and increases cost
Planning	Season Year(s)	**Interday / seasonal balancing**	**Moderate to high** Dependent on resource mix, seasonality of renewable resource	**Low to moderate** Dependent on seasonality of demand and ability to operate plant seasonally	**Low to moderate** Following load lowers capacity factor, and increases cost substantially
			Primary focus of this analysis		

There is a wide range of potential flexibility resources…

Supply side measures

Operating existing plants more flexibly
- Coal
- Gas
- Storage hydro
- Run-of-river hydro

Build new flexible plant
- Flexible gas
- Hydro
- Concentrated Solar
- Biomass
- Tidal or wave power

Renewable curtailment
- Existing utility scale wind and solar
- New utility scale wind and solar
- Distributed solar curtailment
- Improved forecasting

Delayed Plant retirement
- Coal
- Gas

Demand side measures and demand response

Industrial
- Steel, aluminum
- Chemicals
- Pulp and paper
- Cement
- Manufacturing

Commercial/residential
- Heating, Cooling
- Lighting
- Water heating
- Data centers
- Refrigeration
- Appliances & electronics

Water and waste
- Pumping
- Desalination

Real time pricing and behavioral response
- By sector

Automation/Direct control
- Consumer aggregation
- Other by sector

Conversion to other energy forms

Heat and thermal inertia
- Storage Heating
- Storage Cooling
- CHP and district heating

Transport
- Light vehicle charging
- Fleet LV charging
- Bus and rail

Hydrogen production and similar
- Hydrogen production and storage
- Synthetic fuels
- Fertiliser

Other industrial products
- Production and storage of chemicals
- Steel
- Cement
- Etc.

Direct electricity storage

Batteries
- Lithium ion
- Lead Acid
- Zinc Bromine flow
- Other Flow batteries
- Lithium Air
- Solid State
- Aqueous saltwater

Flywheels

Supercapacitors

Pumped storage hydro
- Pure pumped storage
- Mixed pump-reservoir storage

Compressed air energy storage

Infrastructure

Existing infrastructure
- Improved balancing and control

New transmission
- Intraregional reinforcement
- Interconnection and regional expansion

Transmission smart grid technologies
- SCADA, etc

New distribution
- Reinforcement
- Active transmission elements (capacitors, management systems, etc.)

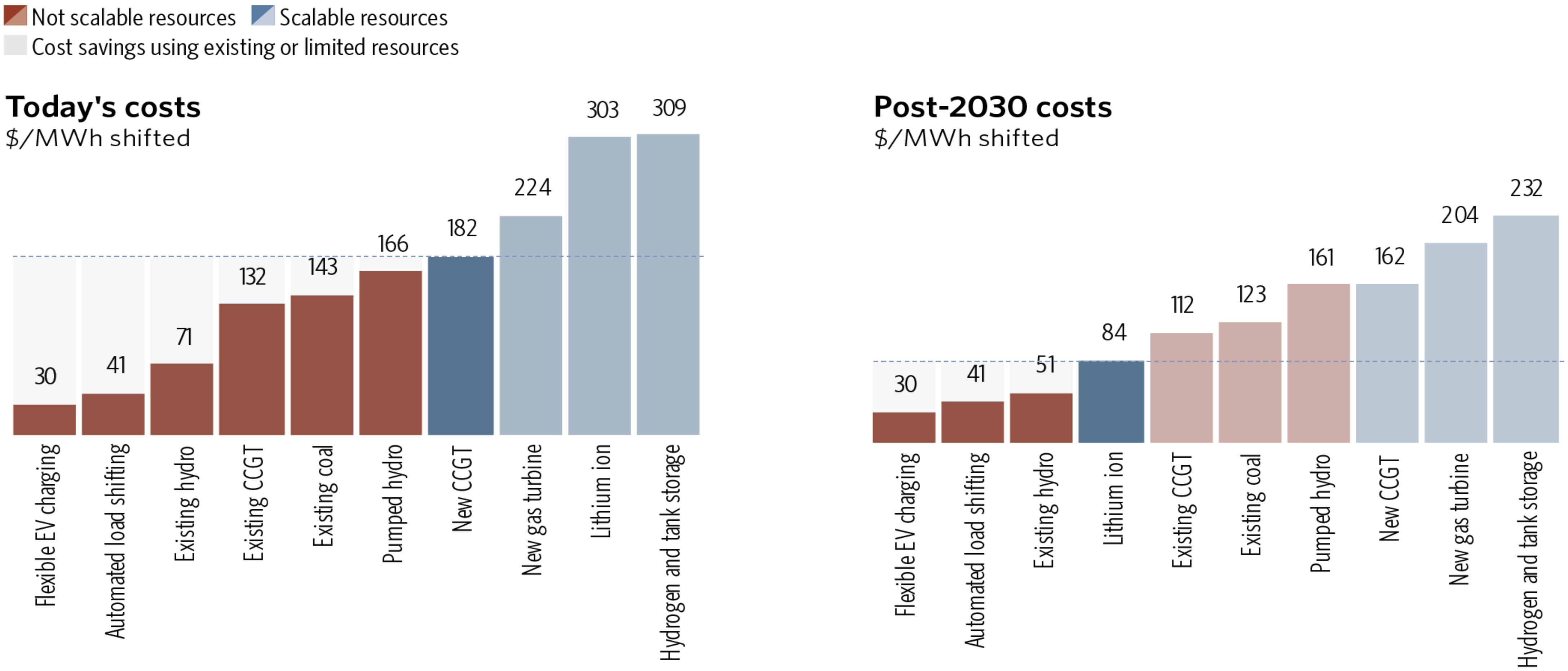
Distribution smart grid technologies
- Control systems and automation

Developing a range of flexibility options will lower the cost of a renewable energy based system further…

Developing Flexibility

On a typical day, flexible loads and existing resources are the most cost-effective options today for daily shifting, but future declines in lithium ion costs will yield cheaper alternatives

Cost of daily shifting (30% capacity factor)

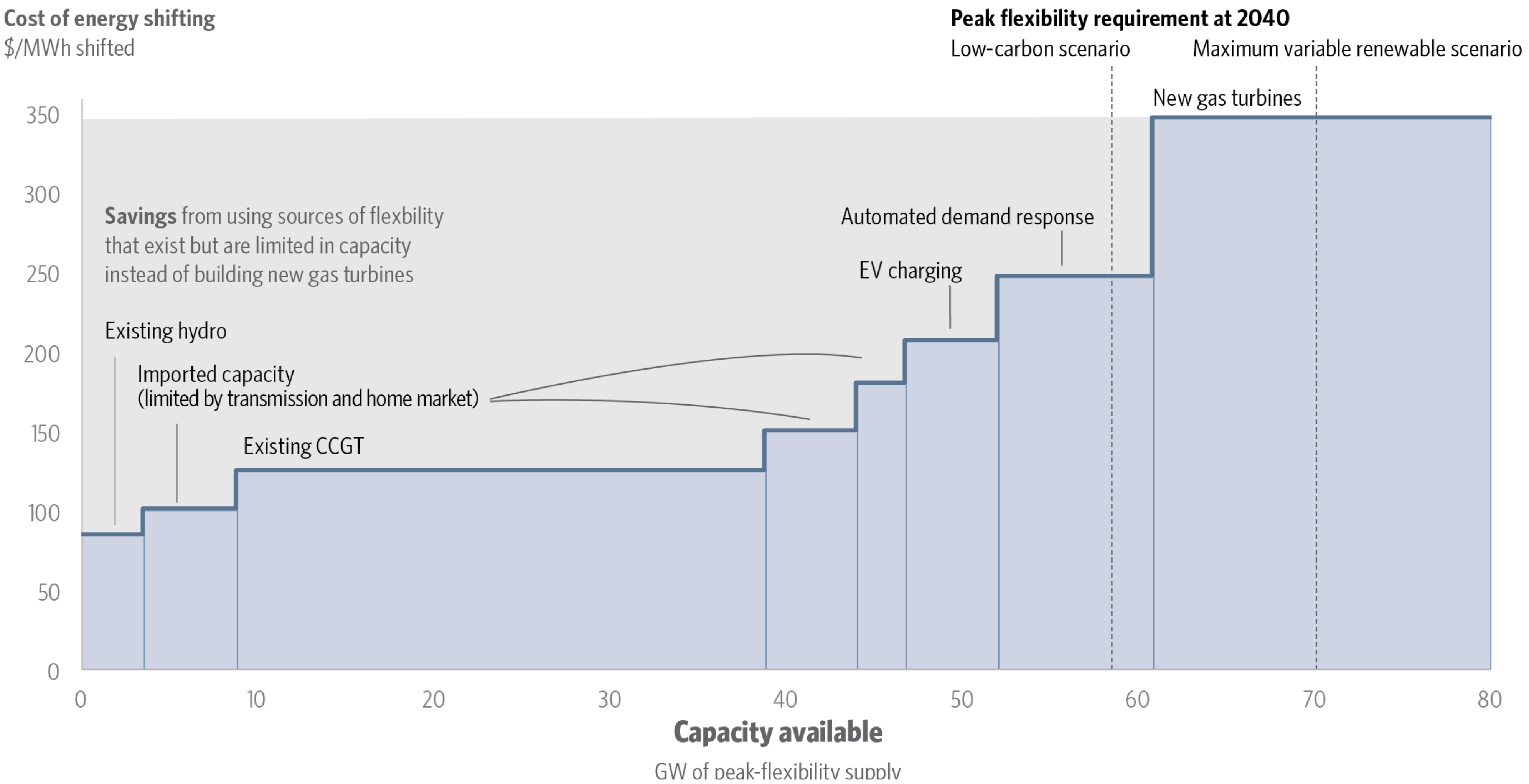


As will optimizing the use of existing flexible capacity, including existing hydroelectric capacity and demand response potential

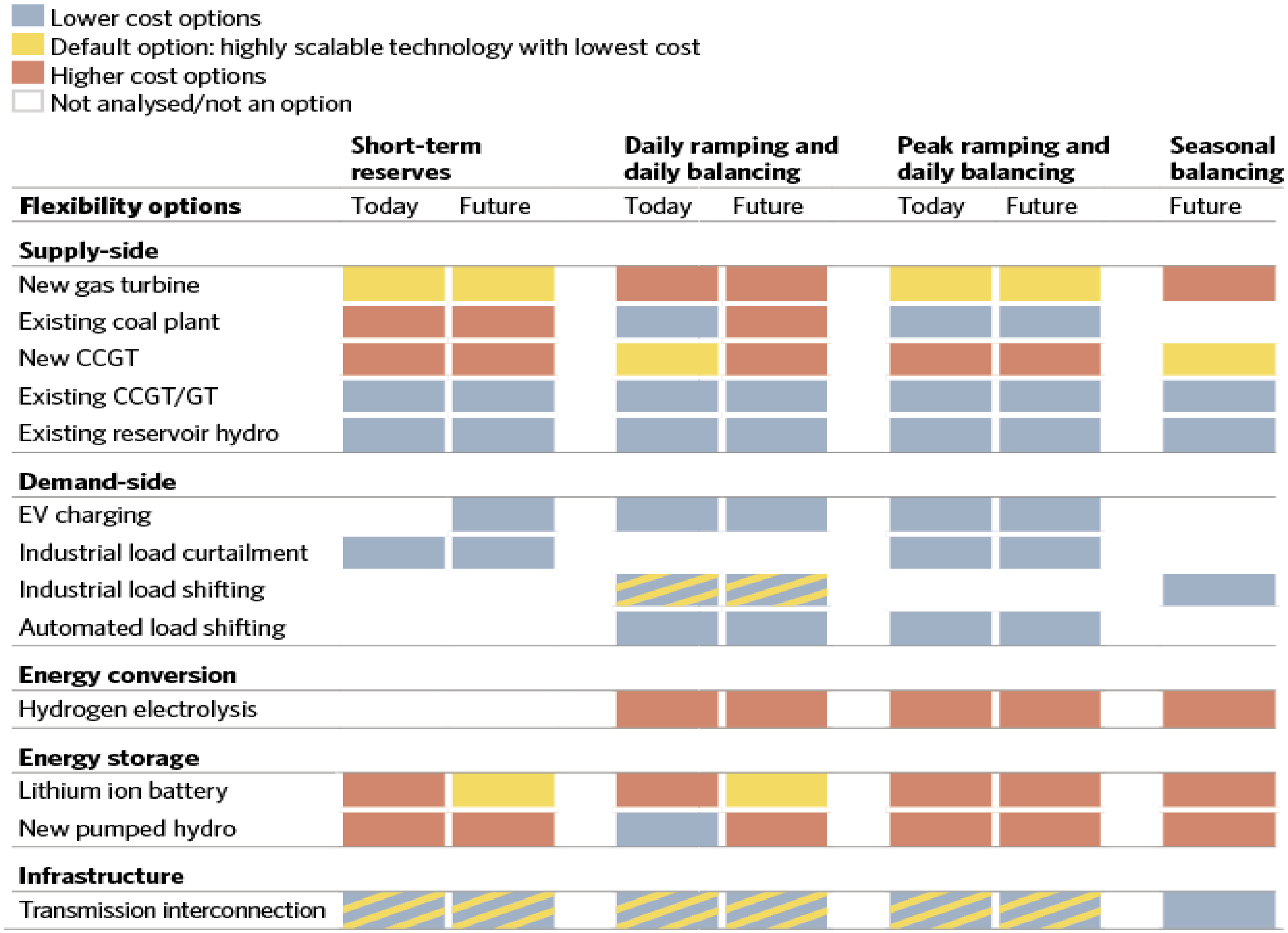
Developing Flexibility

Using the lowest-cost peak daily shifting options

Illustrative cost and supply of California peak daily shifting options in 2040



The relative cost-effectiveness of these options will evolve over time



🟦 Lower cost options
🟨 Default option: highly scalable technology with lowest cost
🟧 Higher cost options
⬜ Not analysed/not an option

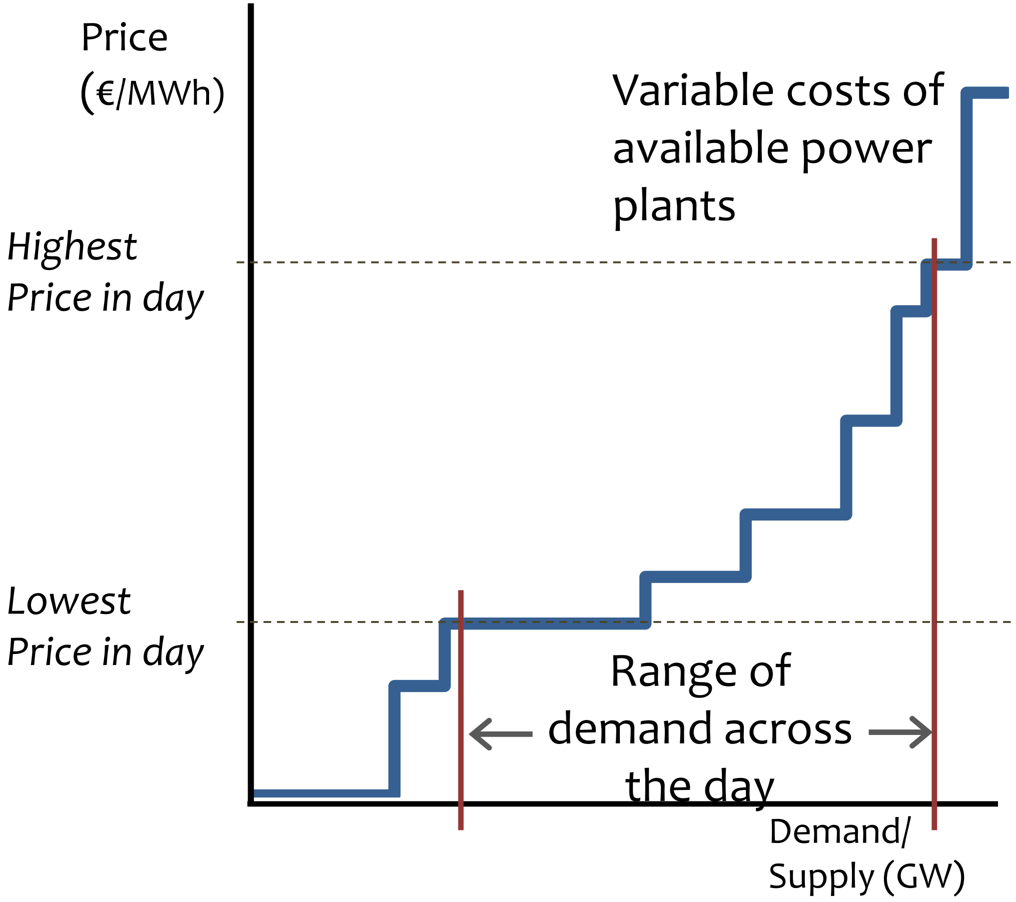
	Short-term reserves		Daily ramping and daily balancing		Peak ramping and daily balancing		Seasonal balancing
Flexibility options	Today	Future	Today	Future	Today	Future	Future
Supply-side							
New gas turbine	🟨	🟨	🟧	🟧	🟨	🟨	🟧
Existing coal plant	🟧	🟧	🟦	🟧	🟦	🟦	
New CCGT	🟧	🟧	🟨	🟧	🟧	🟧	🟨
Existing CCGT/GT	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Existing reservoir hydro	🟦	🟦	🟦	🟦	🟦	🟦	🟦
Demand-side							
EV charging		🟦	🟦	🟦	🟦	🟦	
Industrial load curtailment	🟦	🟦			🟦	🟦	
Industrial load shifting			▨	▨			🟦
Automated load shifting			🟦	🟦	🟦	🟦	
Energy conversion							
Hydrogen electrolysis			🟧	🟧	🟧	🟧	🟧
Energy storage							
Lithium ion battery	🟧	🟨	🟧	🟨	🟧	🟧	🟧
New pumped hydro	🟧	🟧	🟦	🟧	🟧	🟧	🟧
Infrastructure							
Transmission interconnection	▨	▨	▨	▨	▨	▨	🟦

Existing electricity market designs create risks where they do not need to be, and in so doing raise the cost of finance and energy significantly

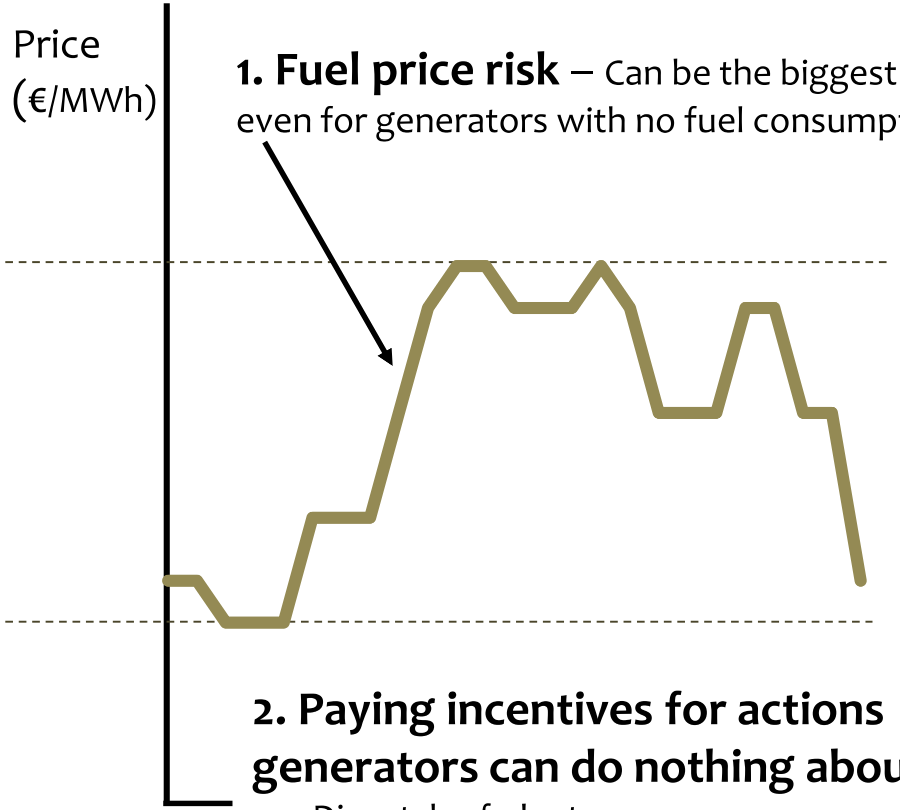
Issues with current designs

ISSUES

Basic price formation in hourly electricity markets



Resulting hourly electricity prices



1. Fuel price risk – Can be the biggest risk even for generators with no fuel consumption

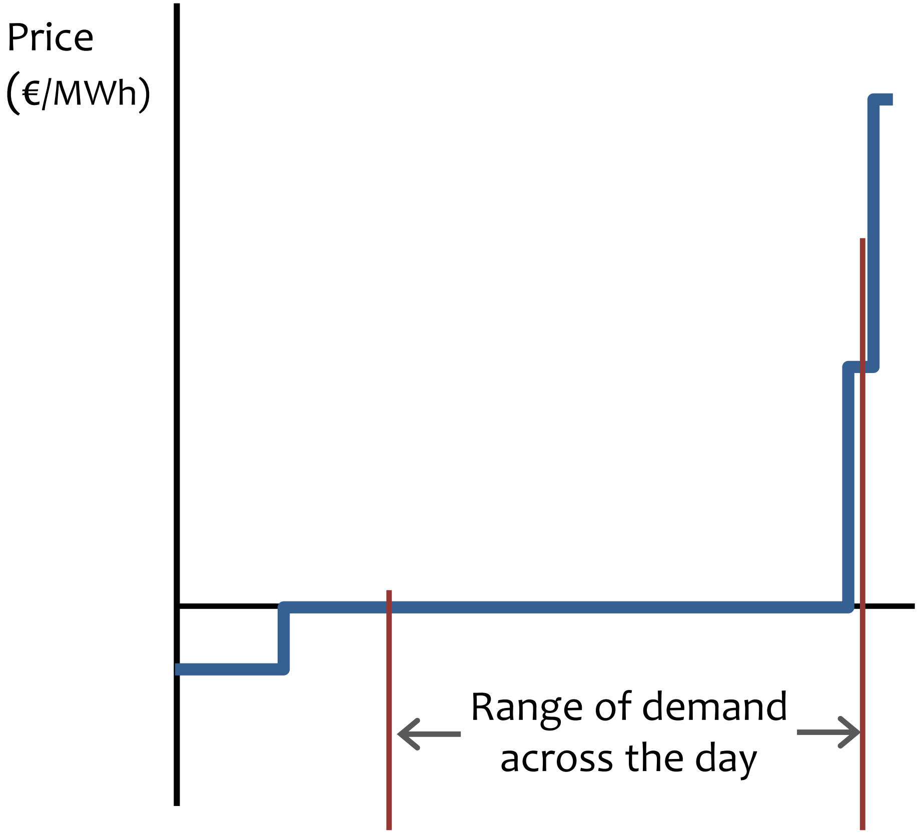
2. Paying incentives for actions generators can do nothing about

- Dispatch of plant
- Improving plant fuel consumption efficiency

When renewables or other zero marginal cost generation become major sources, further weaknesses develop

Issues with current designs

Electricity supply curve with nuclear and renewables at zero marginal price



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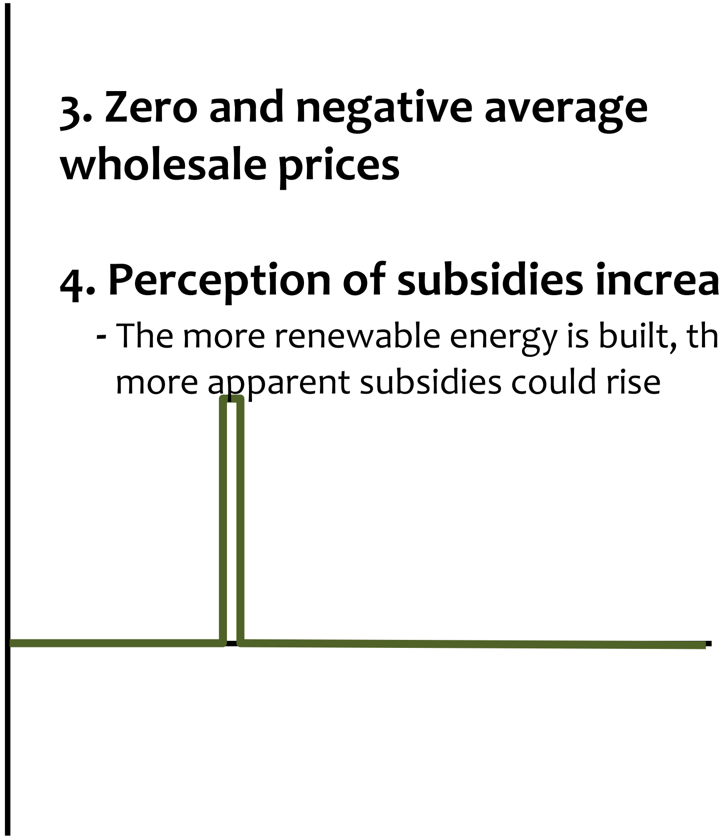


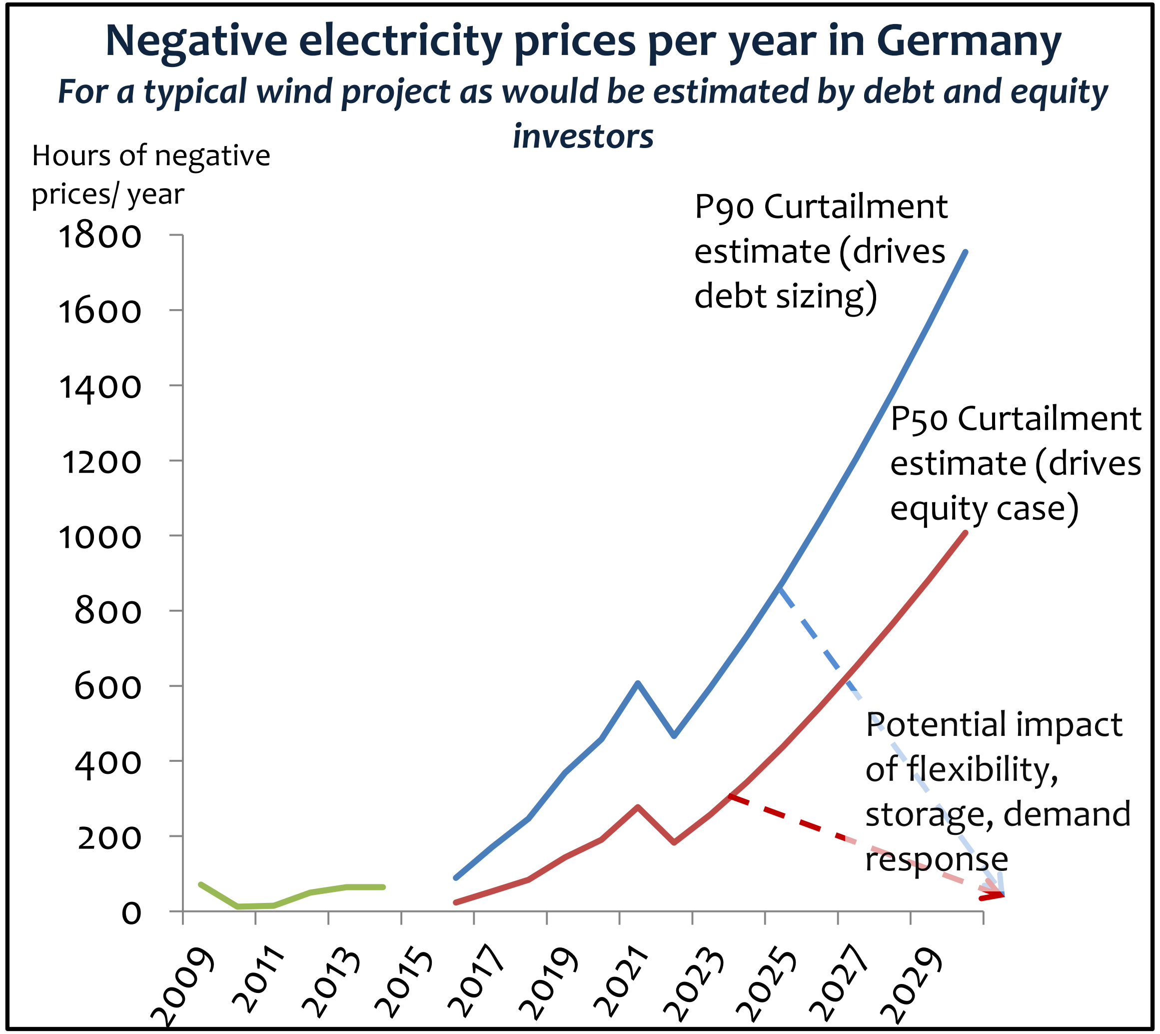
3. Zero and negative average wholesale prices

4. Perception of subsidies increase

- The more renewable energy is built, the more apparent subsidies could rise

The curtailment debate shows how this market failure could increase system costs and make renewable energy uncompetitive

The number of hours with negative electricity prices in Germany will rise rapidly with the current market structure, unless flexibility is increased markedly

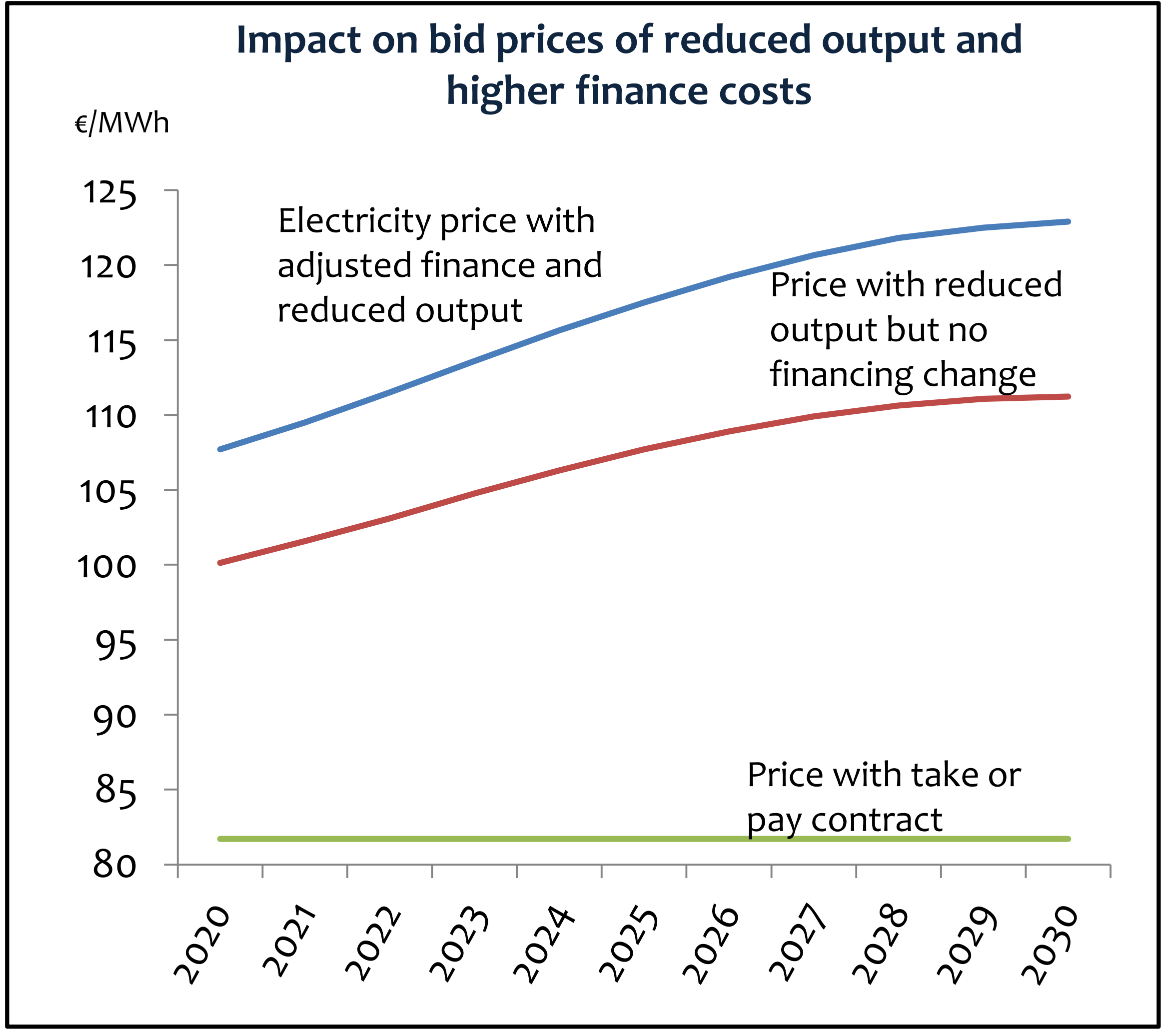


Negative electricity prices per year in Germany

For a typical wind project as would be estimated by debt and equity investors

Source: CPI Analysis (see Policy and Investment in German Renewable Energy (2016)

If renewable electricity producers are forced to curtail with no compensation when prices are negative, costs will rise as a result of reduced output and higher finance costs due to risk



Impact on bid prices of reduced output and higher finance costs

A two market design – separating fixed energy supply and flexibly delivery – can balance finance costs, incentives, and risks, leading to lower costs

A way forward

Objectives

Keep finance costs low

Match risks and incentives to timeframe when decisions are made

- For infrastructure this is typically at final investment decision
- Flexibility operators need continual and shifting incentives

Match risk profile to underlying economics and the appropriate, low-cost investors.

- For infrastructure, typically long-term investors with lower risk tolerance such as pension funds and insurance
- Flexibility investors can respond to greater risk

Target technologies/Services: High fixed cost, low variable cost infrastructure such as renewable energy, nuclear, CCS and transmission and distribution capacity investment

Energy Market

Long term contract and auction based

Incentivize development, deployment and dispatch of flexible resources

Provide incentives covering:

- **Each type of flexibility**, including locational delivery and consumption of energy
- **Efficient dispatch** of available, existing capacity of flexible resources
- **Development of new capacity**
- **De-risking of technology development**

Target technologies/Services: Flexible resources including: fossil and hydro power plants, storage, demand response, transmission and distribution capacity allocation

Delivery Market

Short-term marginal price based, but with separate mechanisms for capacity and technology development and some ancillary services

Redefining a wholesale market to reflect the risks and decision making timing of new energy sources could follow the model already used in Brazil

Energy Market

A wholesale market built around:

- Annual or biannual auctions offering:
- Long term contracts for energy supply, where:
- Pricing is independent of when, or where, the energy is taken.*

This market would:

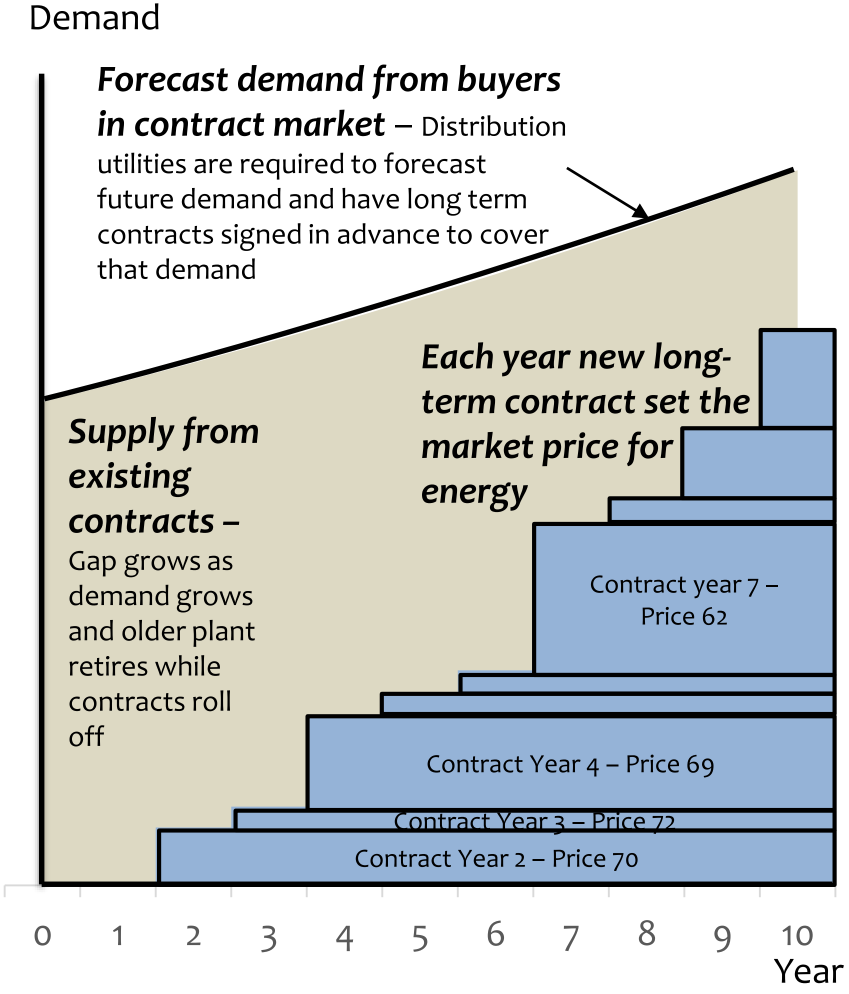
- Match supply and demand and create a market for secure, long term, energy purchase contracts
- Provide investor security to minimize finance costs.

Significantly, the energy market becomes the benchmark energy price.

* *Within a delivery year*

Example: Brazillian new energy markets

Annual auctions to meet demand in auctions

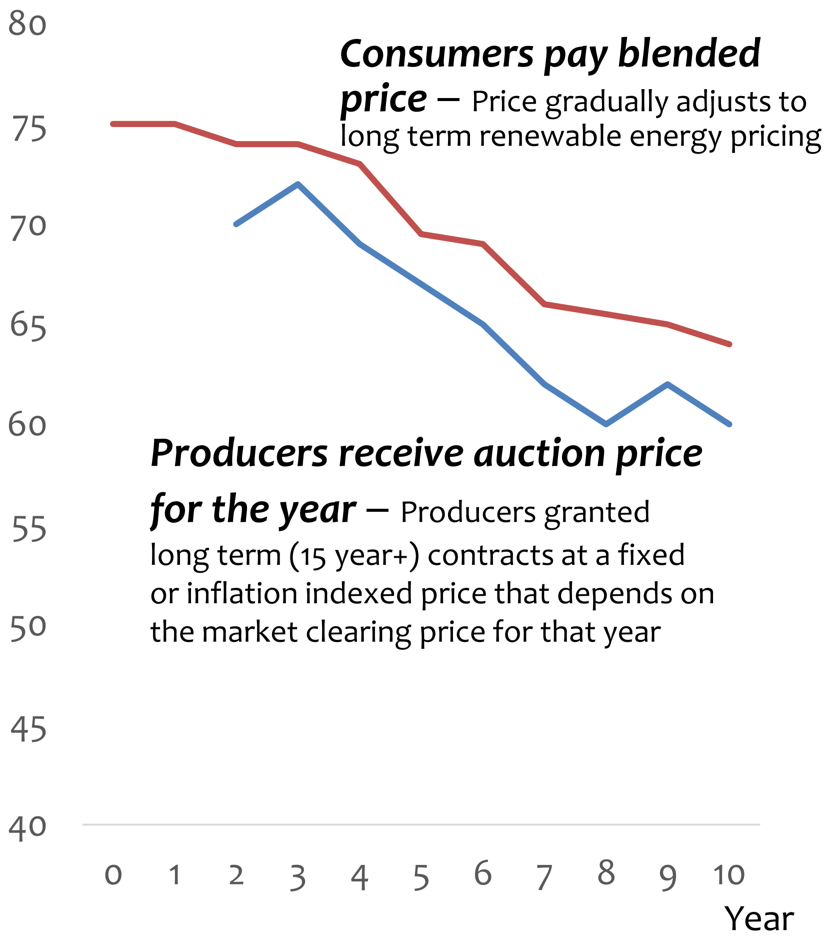


Forecast demand from buyers in contract market – Distribution utilities are required to forecast future demand and have long term contracts signed in advance to cover that demand

Supply from existing contracts – Gap grows as demand grows and older plant retires while contracts roll off

Each year new long-term contract set the market price for energy

Consumers and producers receive energy prices based on that auction



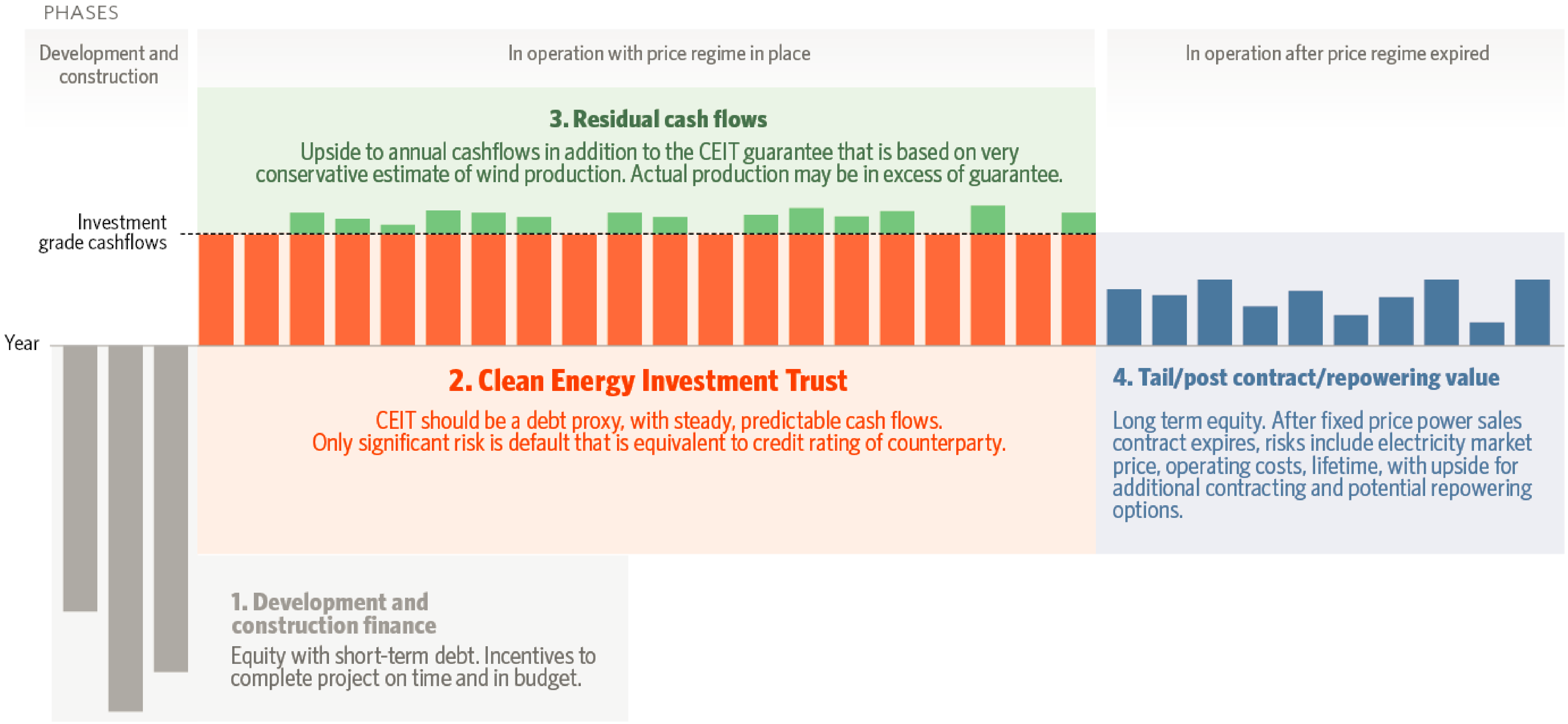
Consumers pay blended price – Price gradually adjusts to long term renewable energy pricing

Producers receive auction price for the year – Producers granted long term (15 year+) contracts at a fixed or inflation indexed price that depends on the market clearing price for that year

New financial structures can build off of appropriate market designs and reduce costs per kWh a further 15-20 percent – Example of the clean energy investment trust

A way forward

The clean energy investment trust



PHASES

Development and construction

In operation with price regime in place

In operation after price regime expired

3. Residual cash flows

Upside to annual cashflows in addition to the CEIT guarantee that is based on very conservative estimate of wind production. Actual production may be in excess of guarantee.

Investment grade cashflows

Year

2. Clean Energy Investment Trust

CEIT should be a debt proxy, with steady, predictable cash flows.
Only significant risk is default that is equivalent to credit rating of counterparty.

4. Tail/post contract/repowering value

Long term equity. After fixed price power sales contract expires, risks include electricity market price, operating costs, lifetime, with upside for additional contracting and potential repowering options.

1. Development and construction finance

Equity with short-term debt. Incentives to complete project on time and in budget.

Delivery markets can adapt current locational marginal pricing electricity market models, but with some key differences

A way forward

Delivery Market

Pass through of energy cost

Charges consumers – or their suppliers - with long term energy purchase, for:

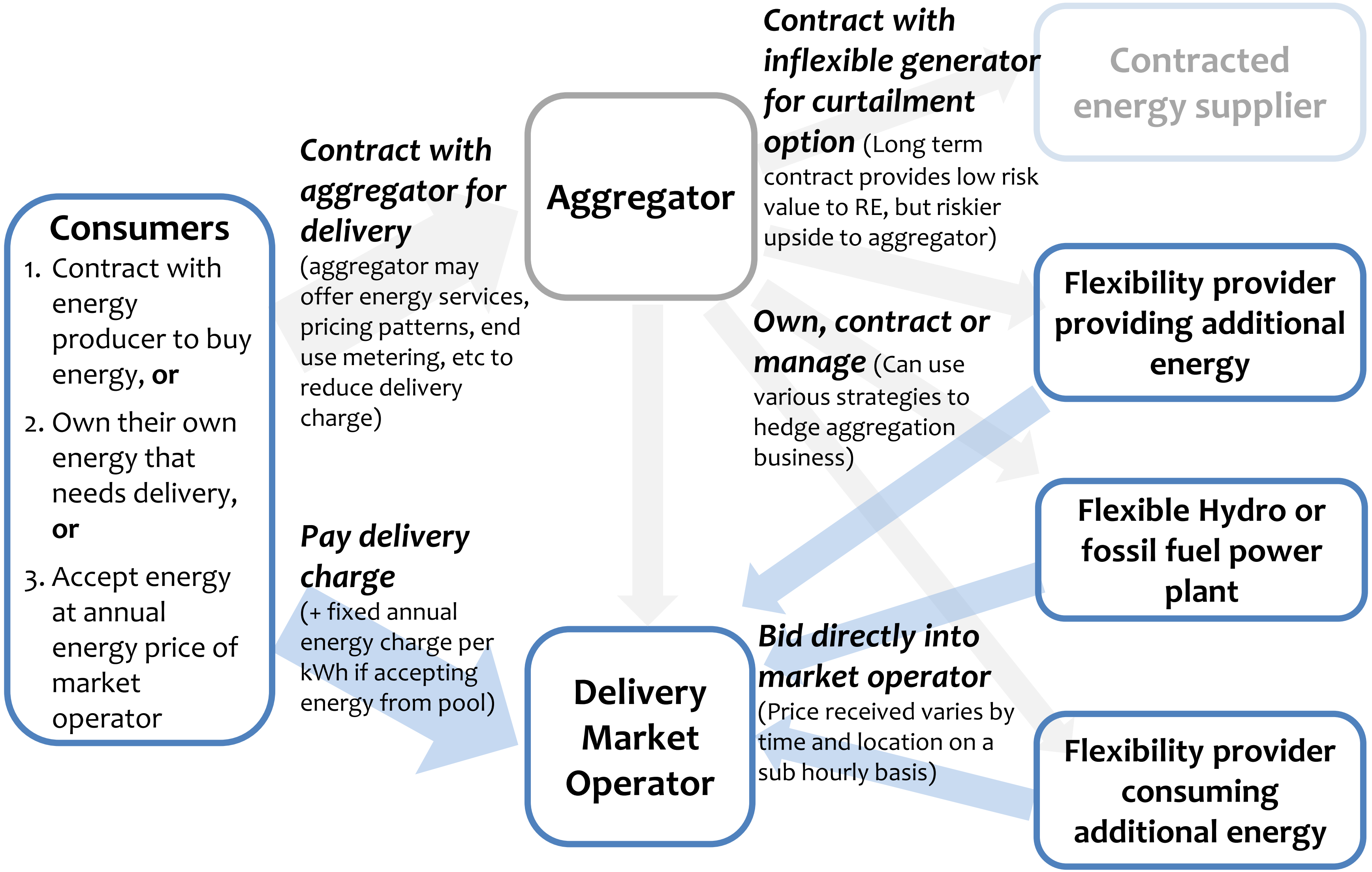
- Delivery costs including transmission and distribution
- Based on the time and location of when the energy is delivered

Prices could vary from strongly negative to highly positive.

Flexible generators, storage providers, and demand response aggregators could all participate into this market.

This market could be based on modified versions of locational marginal pricing markets – such as PJM in the US – but with a pass through of energy costs from the energy market

Aggregators and delivery market operator playing clearinghouse roles in the delivery market



Consumers

1. Contract with energy producer to buy energy, **or**
2. Own their own energy that needs delivery, **or**
3. Accept energy at annual energy price of market operator

Contract with aggregator for delivery (aggregator may offer energy services, pricing patterns, end use metering, etc to reduce delivery charge)

Pay delivery charge (+ fixed annual energy charge per kWh if accepting energy from pool)

Aggregator

Delivery Market Operator

Contract with inflexible generator for curtailment option (Long term contract provides low risk value to RE, but riskier upside to aggregator)

Contracted energy supplier

Own, contract or manage (Can use various strategies to hedge aggregation business)

Flexibility provider providing additional energy

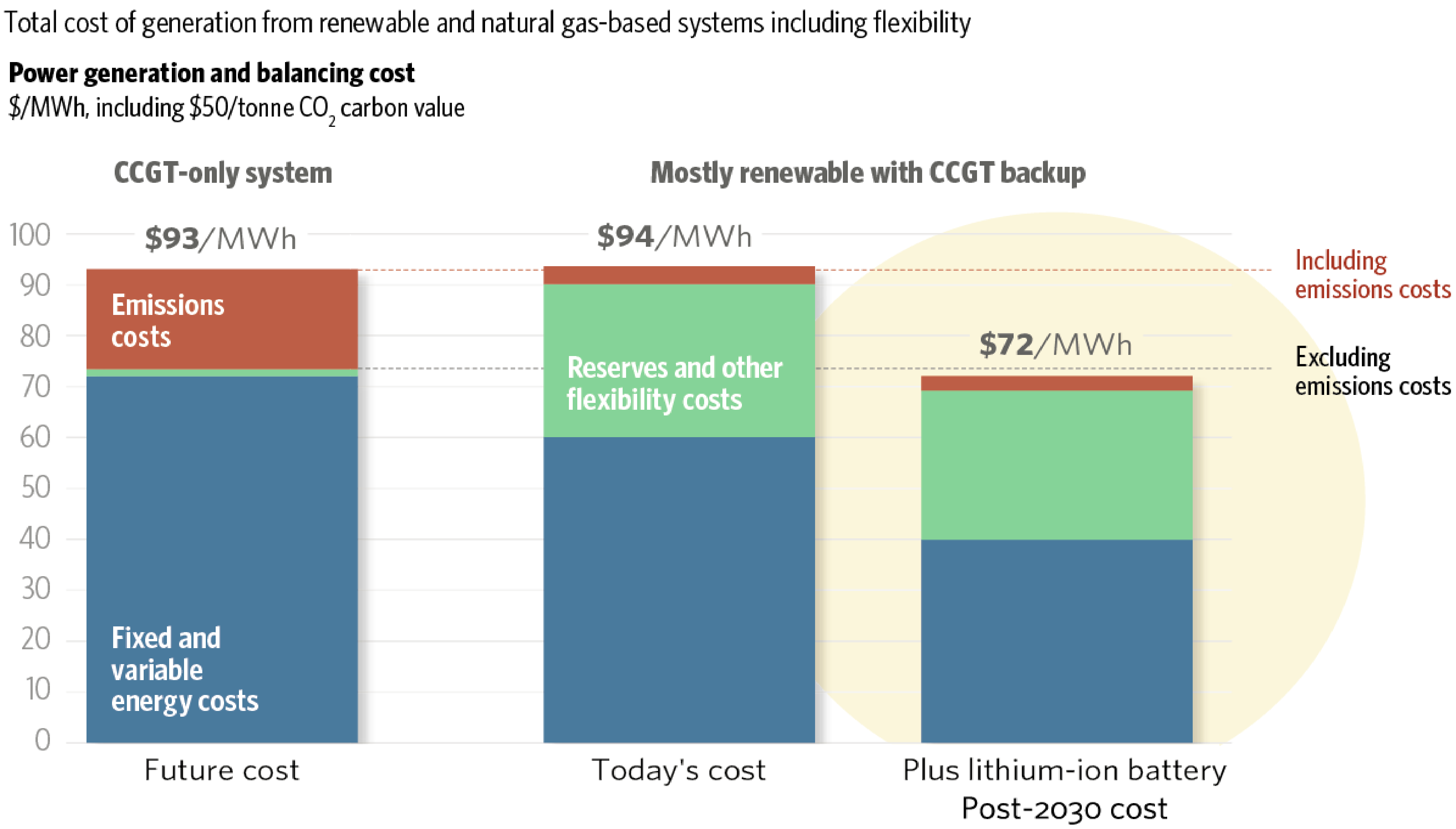
Flexible Hydro or fossil fuel power plant

Bid directly into market operator (Price received varies by time and location on a sub hourly basis)

Flexibility provider consuming additional energy

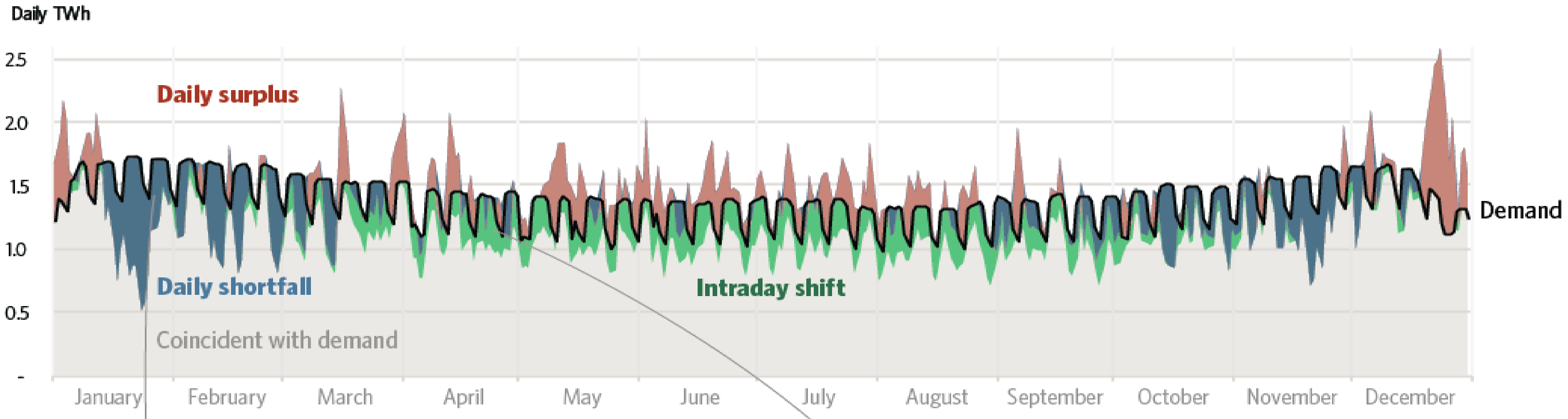
Backup

With the right market design, by 2030 a new electricity system based almost entirely on variable renewable energy could be cheaper than a gas based system



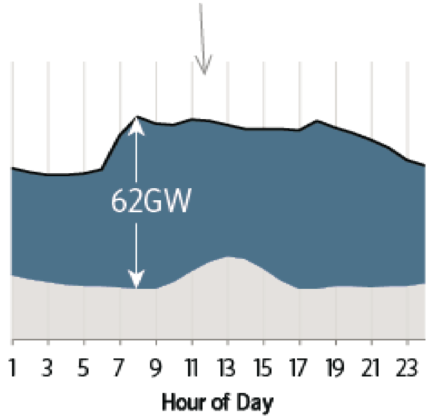
In our example, we based flexibility costs German load shape and renewable energy generation profiles

Daily demand versus renewable energy production profile

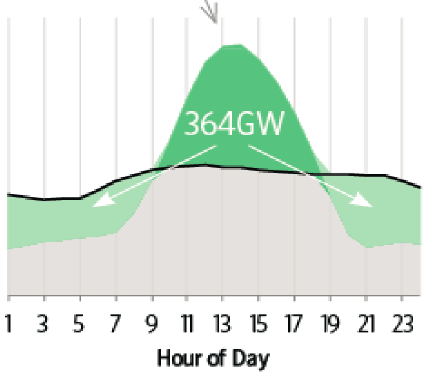


Intraday shifting requirement over the course of the year

Higher resolution sections of figure 1.3

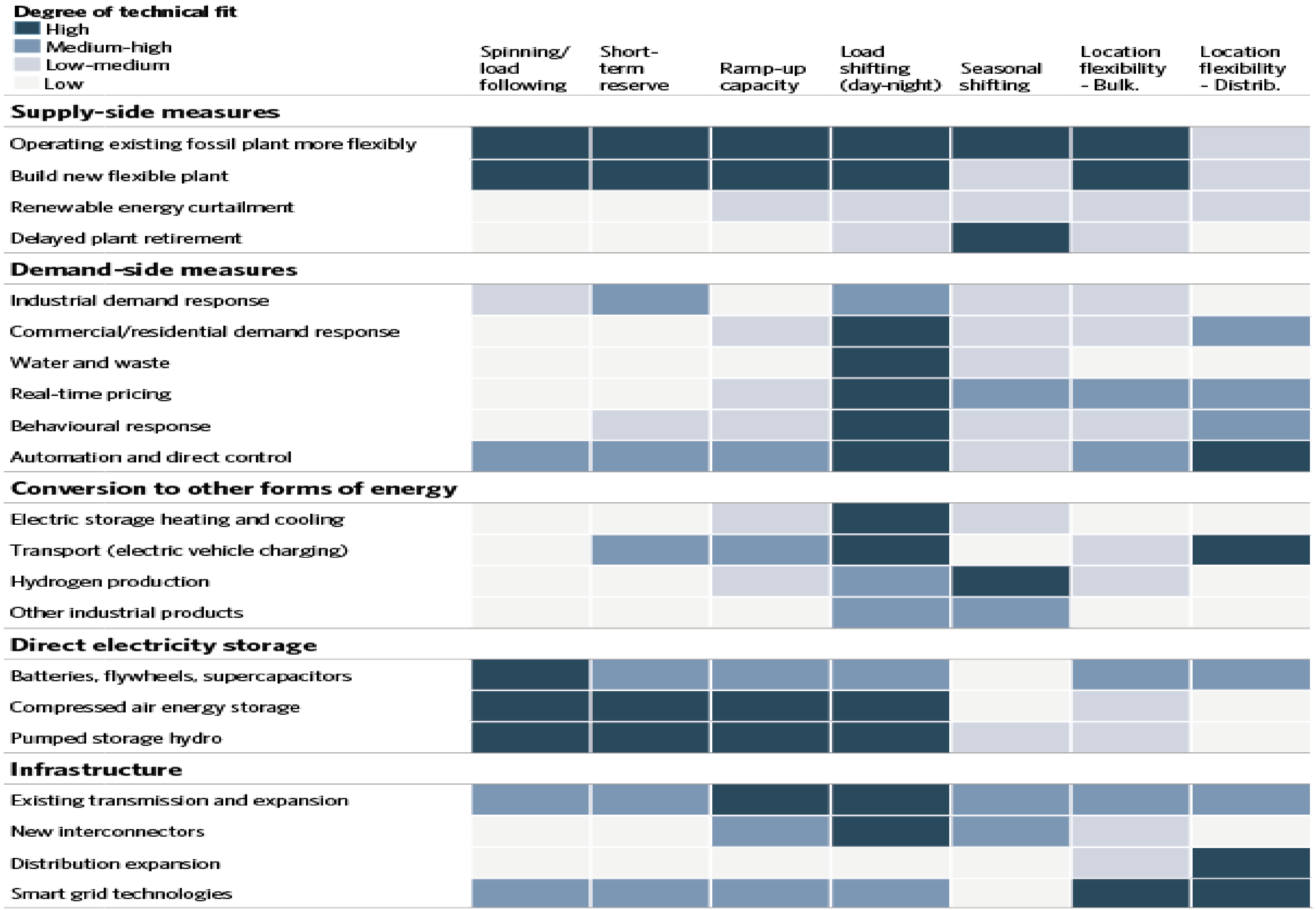


Capacity need on biggest shortfall day
Backup peaking capacity is based on the largest difference between electricity demand and total renewable energy production, which in the model would have reached 62GW on a cold, windless January day.



Intraday shifting on highest shifting day
Daily storage capacity is based on the peak daily storage needs for a mild, sunny, windy day in late April where 364GWh of daytime energy production would need to be shifted to the night.

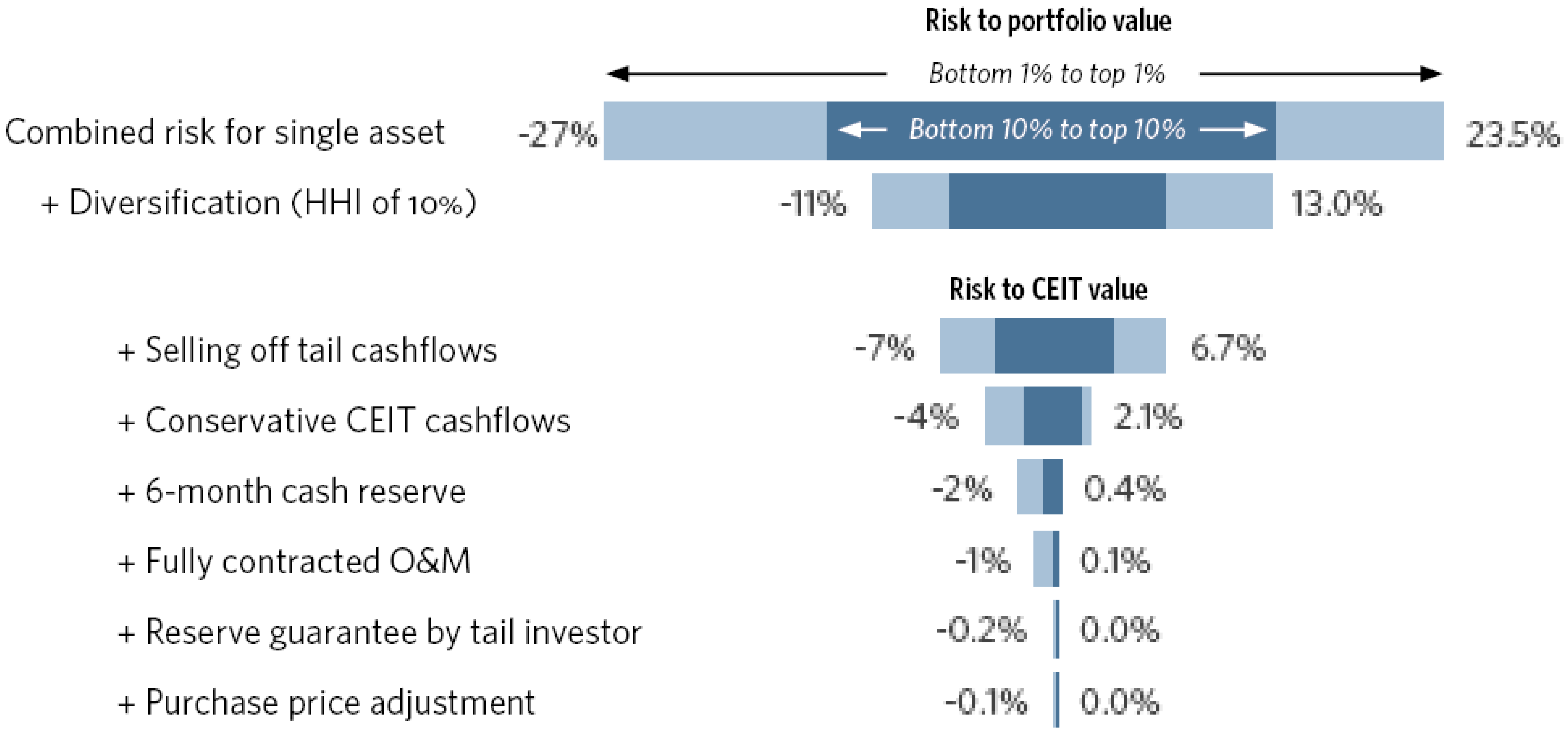
While our analysis was based on "default" technologies, we also assessed a range of technologies and matched them against the various flexibility needs



Degree of technical fit
- █ High
- ▓ Medium-high
- ▒ Low-medium
- ░ Low

	Spinning/ load following	Short-term reserve	Ramp-up capacity	Load shifting (day-night)	Seasonal shifting	Location flexibility - Bulk.	Location flexibility - Distrib.
Supply-side measures							
Operating existing fossil plant more flexibly	█	█	█	█	█	█	▒
Build new flexible plant	█	█	█	█	▒	█	▒
Renewable energy curtailment	░	░	▒	▒	▒	▒	▒
Delayed plant retirement	░	░	░	▒	█	▒	░
Demand-side measures							
Industrial demand response	▒	▓	░	▓	▒	▒	░
Commercial/residential demand response	░	░	▒	█	▒	▒	▓
Water and waste	░	░	░	█	▒	░	░
Real-time pricing	░	░	▒	█	▓	▓	▓
Behavioural response	░	▒	▒	█	▒	▒	▓
Automation and direct control	▓	▓	▓	█	▒	▓	█
Conversion to other forms of energy							
Electric storage heating and cooling	░	░	▒	█	▒	░	░
Transport (electric vehicle charging)	░	▓	▓	█	░	▒	█
Hydrogen production	░	░	▒	▓	█	▒	░
Other industrial products	░	░	░	▓	▓	░	░
Direct electricity storage							
Batteries, flywheels, supercapacitors	█	▓	▓	▓	░	▓	▓
Compressed air energy storage	█	█	█	█	░	▒	░
Pumped storage hydro	█	█	█	█	▒	▒	░
Infrastructure							
Existing transmission and expansion	▓	▓	█	█	▓	▓	▓
New interconnectors	░	░	▓	█	▓	▒	░
Distribution expansion	░	░	░	░	░	▒	█
Smart grid technologies	▓	▓	▓	▓	░	█	█

Careful financial engineering alongside PPAs or the right market design can allow CEITs to achieve investment grade security without equity tranches



Policymakers should set ambitious low-carbon targets and develop flexibility solutions through technology support, market design, industry structure and long-term planning

Finding	What policymakers should think about
Renewable energy ambition *Solutions are available now on most systems to accommodate high proportions of renewable energy at a reasonable cost*	- **Feel free to set ambitious renewable energy targets** to meet their low-carbon objectives. - **Focus on optimising the costs of today's flexibility options**, while setting policy that will deliver increased flexibility capacity in time to meet targets for decarbonising the power sector at the lowest possible cost.
Portfolio approach *No single technology, market mechanism, or flexibility resource will be able to meet all flexibility requirements across all regions*	- **Promote the development and cost reduction of several technologies and flexibility resources**, while creating markets and policy for cost-effective integration of these resources as they develop. - **Create solutions that can contribute to delivering the needed flexibility at a competitive cost include:** Using existing generation capacity differently; increasing demand side flexibility; increasing and optimizing new electrification; restructuring transmission and distribution; developing new roles for batteries; and building some new gas turbines as additional support.
Transition framework *New policy, market and regulatory mechanisms are needed to cost effectively develop flexibility for a high variable renewable energy system*	- **Focus planning and policy development on the transition path to a much higher variable renewable energy system**, while markets need to be configured to get the best output, lowest cost and lowest risk from both renewable energy and the evolving flexibility resources. - **Design markets with long term signals for investment in the transition;** better signals to consumers; markets that differentiate between the supply of energy and flexibility; mechanisms that balance sources of renewable energy to reduce flexibility needs; and process and price signals to improve regional coordination.
Planning horizons *Longer-term planning horizons are needed to develop new flexibility solutions and avoid lock-in of long-term solutions that do not align with transition goals*	- **Create markets and policy that incentivise long-term innovation and balance this innovation against near-term objectives.** For example, there is a continued role for existing fossil fuel generation to ease the transition, while innovation policy and long-term planning is needed to access some of the lowest cost future resources.

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