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NORWEGIAN RESEARCH CENTRE FOR HYDROPOWER TECHNOLOGY

HydroCen Report nr. 42

HydroFy Final Report

Recent developments in European power market design – with implications for hydropower

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HydroCen

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Aubin, V., Belsnes, M., Korpås, M., 2023. HydroFy Final Report: Recent developments in European power market design – focusing on hydropower. HydroCen rapport 42. Norwegian Research Centre for Hydropower Technology

Trondheim, December 2023

ISSN: 2535-5392 (digital publikasjon, Pdf)
ISBN: 978-82-93602-43-9

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Power market design
Europe
Energy transition

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Abstract

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The ongoing energy transition is profoundly transforming power systems. The change of paradigm that is taking place in the power sector leads to questioning the current market design. As reservoir hydropower is a renewable, low-carbon, dispatchable, and cheap source of electricity, it will play an essential role in decarbonized power systems. This report gives an overview of recent developments in European power market design, with a focus on hydropower. It presents general trends related to the energy transition, recently implemented measures and market designs that are considered for implementation in Europe. We observe that power market design creates conflicts between and within dimensions of the energy trilemma. Moreover, various constraints and failures in wholesale markets create a need for complementary markets. Alternative market designs need to be assessed, namely to understand their impacts on hydropower so that it contributes to achieving reliable, sustainable and affordable future power systems.

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Sammendrag

Aubin, V., Beslnes, M., Korpås, M., 2023. HydroFy Final Report: Recent developments in European power market design – focusing on hydropower. HydroCen rapport 42. Norwegian Research Centre for Hydropower Technology

Den pågående energiomstillingen er i ferd med å forandre kraftsystemene. Paradigmeskiftet som finner sted i kraftsektoren, fører til at det stilles spørsmål ved dagens markedsdesign. Ettersom vannkraft i magasiner er en fornybar, har lavt karbon avtrykk, er en regulerbar og billig strømkilde, vil vannkraft spille en viktig rolle i avkarboniserte kraftsystemer. Denne rapporten gir en oversikt over den siste utviklingen og publisering omkring det europeiske kraftmarkedet, med fokus på vannkraft. Den presenterer generelle trender knyttet til energiomstillingen, nylig iverksatte tiltak og markedsdesign som vurderes gjennomført i Europa. Vi observerer, at kraftmarkedsdesignet skaper konflikter mellom og innenfor dimensjonene i energitrilemmaet. I tillegg skaper ulike begrensninger og svikt i engrosmarkedene et behov for komplementære markeder. Det er nødvendig å vurdere alternative markedsdesign for å kunne modellere og forstå hvordan de påvirker vannkraften, slik at den best kan bidra til å skape pålitelige, bærekraftige og kostnadseffektive fremtidige kraftsystem.

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Content

List of acronyms

CfD Contract-for-Difference
CO2 Carbon dioxide
CRM Capacity Remuneration Mechanism
EC European Commission
ENTSO-E European Network of Transmission System Operators for Electricity
EU European Union
LMP Locational Marginal Pricing
PPA Power Purchase Agreement
SFPFC Standardized Fixed Price Forward Contracts
SIDC Single Intraday Coupling
TEM Target Electricity Market
VRE Variable Renewable Energy source
XBID Cross Border Intraday

1 Introduction

The ongoing energy transition is profoundly transforming power systems. The decommissioning of thermal power plants combined with increasing shares of Variable Renewable Energy (VRE) poses new for the operation of power grids. New flexibility needs will have to be addressed to maintain reliability levels similar to today's.

The change of paradigm that is taking place in the power sector leads to questioning the current market design. Indeed, the introduction of new technologies in the resource mix, such as wind, solar photovoltaics and battery storage, can make some market imperfections more critical than they used to be. Meanwhile, correcting measures must be introduced carefully to avoid creating other inefficiencies.

Throughout the process, the analysis framework of market design should be based on the energy trilemma: how can we maximize reliability, sustainability, and affordability within our power systems? Illustrated in Fig. 1. These systems are, after all, service providers to society as a whole and not to specific producers or consumers. It should be noted that the economic dimension is affordability, not profitability. Nevertheless, in order to achieve this goal, market design must ensure that all required actors have economic incentives to participate in the market.

As reservoir hydropower is a renewable, low-carbon, dispatchable, and cheap source of electricity, it will play an essential role in decarbonized power systems. Its long-duration storage, as well as its fast response capabilities, make hydropower very valuable with respect to both increased electrification and increased shares of VRE. Meanwhile, hydropower differs from other dispatchable power plants, such as thermal and nuclear ones, through its high dependency on natural factors. For example, hydropower producers must take into account the long-term variability in inflow-dependent generation and the impacts of different operation regimes on the local environment. Moreover, the landscape constrains infrastructure design choices, leading to some plants being more dispatchable than others.

Research is needed to understand how to make hydropower contribute best to power systems faced with the decarbonization challenge. Special attention must be given to the impacts of market design on hydropower to consider and expand its unique capabilities, while respecting its operational constraints and weather dependencies.

This report will first present, in section 2, the research challenge and objectives that the Fair and Inclusive Markets for Hydropower (HydroFy) project tackled. The following sections present the findings on power market design. It starts with recent trends and developments in section 3, and continues with specific power market alternatives in section 4. Relevant considerations for hydropower are added throughout the report. Section 5 concludes the report with a summary of the key takeaways and further work suggestions.

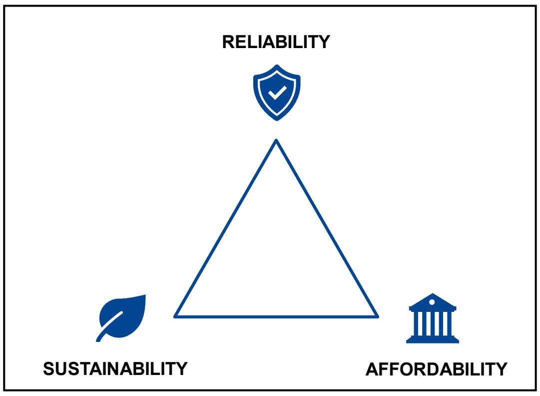


Figure 1, The energy trilemma

2 Research challenge and objectives

2.1 Research challenge

This research provides an overview of recent power market design developments in Europe and their potential impacts on hydropower. Input to the paper is both recent scientific publications, input from the international project workshops and relevant policy documents.

2.2 Main objectives

There are several objectives of the work in the HydroFy project. The starting point is to use resent publications to provide an overview of the trends in the scientific work on power market research and discuss this work from a Norwegian/hydropower perspective enable the full use of hydropower's ability to deliver flexibility within different time horizons, Fig. 2.

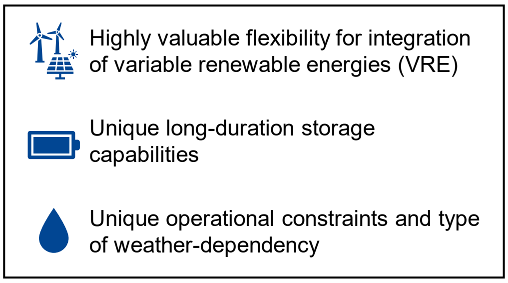


Figure 2 Hydropower abilities

This leads to the following objectives:

- Identify trends in power market design in Europe.
- Increase the knowledge base to achieve a better understanding of challenges and opportunities related to power market design from a hydropower perspective.
- Suggest research gaps to be filled.
- Inform researchers, professionals, and students within the field.

3 Power market design: trends and opportunities

3.1 General trends

The energy transition and climate change introduce greater uncertainties and complexities in the electricity market. Newbery (2016) makes the distinction between the “missing money” and the “missing markets” problems. While market liberalization and competition policies theoretically allow profit-driven generation investment to meet capacity adequacy needs without explicit policy interventions, the presence of "missing money" and "missing market" problems can hinder this. "Missing money" arises when revenue from existing markets is insufficient to cover costs, capital expenditures (CAPEX) and operating expenses (OPEX), due to low price caps or inadequate remuneration, creating a need for support through subsidies or new mechanisms. This applies to VRE themselves as well as to resources providing flexibility and capacity services. On the other hand, "missing market" problems occur when there is potential generation adequacy, but investors perceive risks or externalities such as CO2 emissions not being properly priced, making efficient risk management challenging.

3.1.1 Support for VRE

The "missing money" issue in renewable energy occurs when the actual value of renewable generation is not fully compensated in the electricity market, often due to the cannibalization effect. This effect results from high shares of renewable energy, like wind and solar, causing a surplus in supply during periods of high generation as the production of these resources is spatially correlated. This leads to a decline in wholesale electricity prices at those times, and even negative prices as experienced lately. The cannibalization effect refers to the fact that adding more renewables to the power mix amplifies this phenomenon and reduces the revenues that renewable power producers can expect from the wholesale market. The traditional short-term spot price-focused market design may not adequately account for the unique characteristics of renewable energy, making it necessary to consider alternatives such as a carbon price or direct support policies to reflect their societal value properly. (Gerres et al. 2019)

However, the growing maturity of renewable energy investors challenges the idea that renewable energy sources should be shielded from wholesale market risks, with an emerging consensus advocating for their active participation in wholesale markets on equal terms with conventional generators, aligning support policies to ensure full market compatibility. (Huntington et al., 2017)

3.1.2 Incentivizing flexibility

The increasing share of intermittency in energy generation necessitates the development of new market products and services to maintain reliability and efficiency in the system. However, the rise of this zero marginal cost generation diminishes incentives for investment in dispatchable technologies, as declining spot energy prices and flaws in capacity markets impact investment incentives. Joskow argues that the present shift towards a model reliant on subsidies and long-term contracts, guided by centralized resource planning rather than decentralized market incentives, appears unstable and inefficient (Joskow, 2019). Moreover, others argue that the current European market designs do not correctly account for the value of flexibility resources for minimizing the necessary investments in low-carbon generation to meet carbon targets (Strbac et al., 2021).

Joskow (2019) considers storage as a potential solution to intermittency in electricity markets, but recalls that revenues from wholesale markets will have to be sufficient for recovering investment and other costs. Today, in some regions, grid-scale storage providers are treated as both customers and generators with respect to network pricing. This disadvantages them compared to conventional hydropower dams or behind-the-meter storage (Leslie et al., 2020). They are also sometimes imposed fixed costs for transmission, distribution, or out-of-market payments. (Gruenspecht et al., 2022) see it as a problematic hindrance to storage development unless there is a clear cost-causality rationale, such as the creation of transmission interconnection costs. They emphasize the importance of allowing storage providers to participate in capacity and ancillary services markets, acknowledging that the capacity value of storage facilities can vary based on their maximum energy storage duration. They also highlight the potential need for system operators to monitor capacities and resource status for efficient and secure system operations.

3.1.3 Capacity remuneration and hybrid markets

Capacity remuneration seeks to solve the missing-money problem by guaranteeing sufficient electricity generation capacity to cover peak demand. It offers financial incentives for power generators to invest in and maintain the necessary capacity for grid reliability; however, critics raise concerns about potential overcompensation and market distortion (Green and Léautier, 2018). In the energy transition context, capacity mechanisms need adjustments for VRE generation and storage to fully compensate for the stochastic nature of VRE generation and demand and the energy-limited aspect of storage. Another option would be to substitute capacity mechanisms with a greater emphasis on integrated resource planning that adequately incorporates these factors (Gruenspecht et al., 2022).

Joskow foresees a transformation in the energy system, separating the investment and procurement of new generation and storage facilities from short-term markets responsible for economically dispatching these facilities. The regulator could set a renewable energy goal, with a residual mix of dispatchable generation and storage to manage intermittency efficiently. This shift may involve long-term contracts enforced by regulated entities to attract new facilities and ensure system reliability, while the wholesale market would primarily focus on short-term energy dispatch and balancing (Joskow, 2019).

This kind of hybrid market separates long-term investment decisions from short-term operations to facilitate coordinated and de-risked investments while relying on both competitive and regulatory design elements. (Keppler et al., 2022) (Roques and Finon, 2017)

Moreover, Wolak (2021) suggests standardized fixed price forward contracts (SFPFC) to achieve long-term resource adequacy by letting generation bear the risks. He argues that this would be more suitable than capacity-based approaches considering the rising share of renewables, which transfer the resource adequacy problem from the peak load hours to a year-round consideration. The SFPFC approach covers demand at all hours at a fixed price. It encourages generators to provide energy at the lowest cost to maximize their revenues. They get a strong incentive to have their own capacity available at times of scarcity; otherwise, they need to buy energy on the market at a high price. Cross-hedging would be possible, where VRE generators would cover their generation risks while dispatchable generators would cover their income risks.

3.1.4 Forward market design

Uncertainty is rising in the electricity market. This increases the need for efficient forward electricity markets to manage risks and ensure enough investments for a stable energy supply. Today, forward markets seem to offer limited risk hedging because of incompleteness. Although market completeness is hard to assess or quantify, liquidity in forward markets in Europe is low and has decreased steadily in recent years. This might be explained by decreasing trust in long-term prices and missing products, as forward market products are limited for long-term horizons and in terms of granularity. In the long run, the security of supply is affected if investments are perceived as too risky. The absence of a market for long-term contracts incentivizes retailers to under-procure in the forward market, necessitating regulatory intervention, such as a mandated long-term resource adequacy mechanism, to address this missing market and internalize the reliability externality. Rolling blackouts, where random supply curtailments are employed to balance demand and supply under certain system conditions, create a reliability externality as retailers, regardless of their energy procurement strategies, face the same likelihood of being randomly curtailed. The incentive to hedge against such critical conditions is, therefore, low. (Wolak, 2021)

Some potential solutions have been put forward in recent literature. Some advocate for a central buyer model where a public entity would share the risks through financial contracts, providing more stable and predictable revenue streams for energy generators (Finon & Beeker, 2022) Cramton et al. (2023) describe a similar approach to the SFPFC (Wolak, 2021), but for a forward energy market. Frequent (hourly clearing) batch auctions would take place to trade a large number of products (hourly and monthly products) through flow trading (Budish et al., 2023). This paper points to that provider obligations, when combined, would need to cover the whole forecasted demand in the system for the upcoming month, and would decrease linearly for the subsequent four years. The remainder of the market would work on a voluntary basis. It is argued that such a stronger forward energy market would remove the need for capacity remuneration mechanisms. In terms of investments, lead times for new projects are often longer than four years, especially with hydropower. Therefore, the short duration of existing future markets can favour the competitiveness of solutions that have higher carbon emissions than hydropower.

3.2 Recent measures in Europe

3.2.1 Response to the 2022 energy crisis

The energy crisis spurred by the Russian invasion of Ukraine led to discussions on how well the electricity markets function, among many other issues. While some advocated for temporary measures aiming at providing relief to consumers, others were questioning the fundamental principles that power markets rely on. The European Commission's (EC) communications received special attention, as they were suggesting various measures to respond to the high power prices. Some suggestions had implications for power market design, such as price regulation, rent transfer mechanisms (or windfall profit tax), price caps in wholesale markets, and subsidies to fossil fuel-powered electricity generators.

Heussaf et al. (2022) oppose price caps because of the market distortion they entail, possibly leading to higher demand and worsening the energy crisis. On the other hand, they support the rest of the proposition from the EC, and they advocate for splitting the market based on the generation technology (see subsection 4.1.4.) in order to reduce unfair windfall profits.

Batlle et al. (2022b) recall, however, that Europe was going through a "natural gas crisis and not an electricity market crisis (or more precisely, not a short-term electricity market design issue)." They deplore the lack of focus on the potential of natural gas consumption reductions through rationing policy. As stated in (Gran et al., 2023) the power market has proven its worth over time for optimizing the power system. Among the suggested measures from the EC, they identify the windfall profit tax as the one leading to the least inefficiencies, while not recommending it. They emphasize the importance of avoiding introducing regulatory risk in long-term investments and distorting the short-term dispatch. Meanwhile, they argue that other mechanisms might be more helpful in preparing for such extreme events in the long run. These mechanisms include centralized auctions for renewables, a market-maker obligation in organized forward markets and what they call “affordability options”, which would be a sort of insurance taken by a central entity on behalf of certain groups of consumers, as determined by the regulator, against lasting high electricity prices.

Batlle et al. (2023) rejoice in that the short-term power markets were, in the end, not affected by the questioning of its underlying principles and identify weaknesses in the current electricity market design. Meanwhile, they observe that the long-term markets appear to be incomplete and lack liquidity and that the regulatory risk seems higher after this crisis. This led to a debate on whether long-term contracts should be centralized using Contracts for Differences (CfDs) or decentralized through the use of Power Purchase Agreements (PPAs). In the end, the EC seemed more favourable to the widespread use of PPAs, while also advocating for strengthened capacity remuneration mechanisms (CRMs) with a focus on flexibility. The authors criticize this statement, arguing that specific support for flexibility should be introduced if necessary, but should not be combined with tools for capacity.

3.2.2 Intraday market design

As the share of VRE continues to rise, real-time adjustments performed in intraday markets are anticipated to become more important. Moreover, although most trading occurs within specific zones, there is a projected substantial increase in cross-zonal trade in the near future. Efficient pricing and allocation system for cross-border transmission capacity in the intraday timeframe hence receives more attention in parallel to the energy transition. In 2018, the Cross Border Intraday (XBID) project introduced IT infrastructure for an intraday cross-zonal market in the European Union (EU). It is a continuous trading mechanism without pricing for transmission capacity, leading to dispatch and investment distortions. A mechanism with multiple auctions in the intraday timeframe instead of continuous trading could on the other hand enable efficient transmission capacity pricing, inclusion of complex bids and transmission constraints and higher participation from small producers (Ehrenmann et al., 2019). Today, cross-border trading across Europe is still performed through continuous trading through the Single Intraday Coupling (SIDC) structure, an extension of the XBID project (ENTSO-E, 2023).

3.2.3 Storage promotion in Spain

In addition to the changes made in last years to allow energy storage to participate in the system's ancillary services and the markets through which these services are negotiated, on July 20, 2023, the Spanish Ministry for Ecological Transition published a call for proposals for energy storage projects. The funds will be awarded in the form of subsidies.

Up to 150 million euros will be granted to stand-alone electrical energy storage other than pumped-storage and 30 million euros will be granted to thermal energy storage systems. The call for pumped-storage projects has a budget of 100 million euros (max. of 50 million euros per project). There is, hence, a total of 280 million euros for energy storage projects.

The selected projects will have to provide new flexibility to the power sector, namely for integrating VRE. Criteria for the selection include economic viability, technical characteristics (storage capacity, efficiency, inertia and other system services, as well as residual capacity at end-of-life) and externalities like impacts on the local environment or contribution to the local economy. Technical requirements are specified for the different calls in terms of duration and system services to be provided (not for thermal storage) Hybrid power plants and virtual storage plants are not eligible for this call.

Pumped-storage projects cover the addition of new pump or turbine units, new connections between reservoirs, and the conversion of a conventional hydropower plant to a pumped-storage plant, among other things. The duration of storage must be at least eight hours, and the additional capacity must be 25 MW, at the minimum.

Additional support is given to projects located on islands (Canarias and Baleares).

No requirements regarding the operation of the storage facilities are included in the call for proposals. We, therefore, assume that new storage will participate in Spain’s existing power markets on equal terms with existing assets.

4 Power market design options

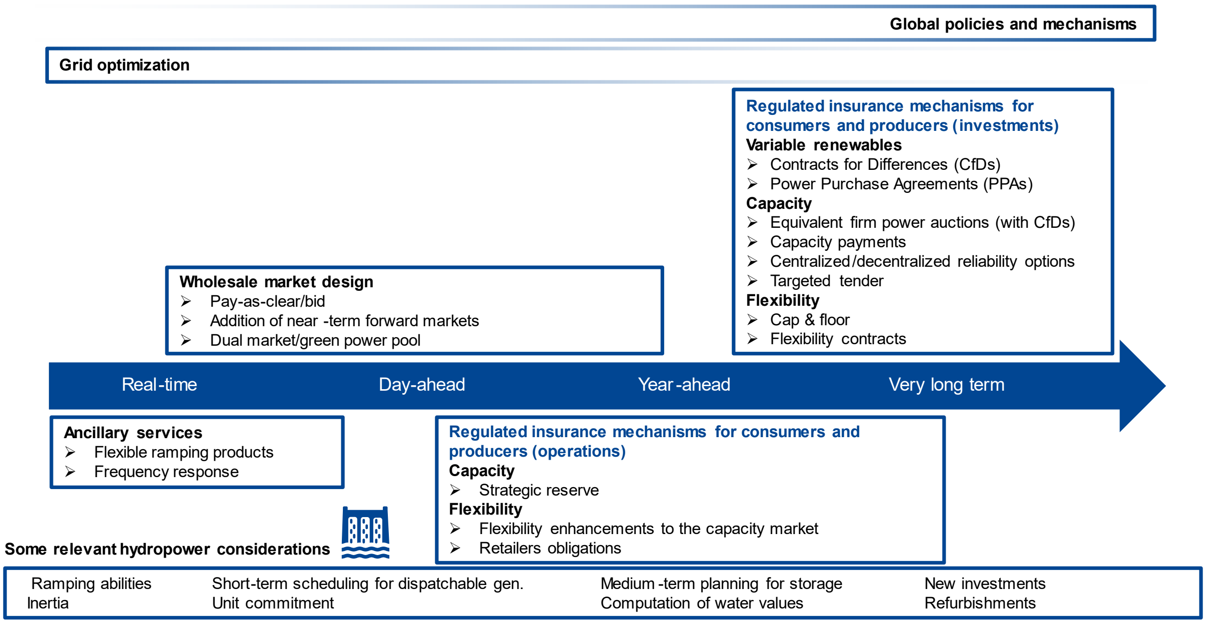
Many power market design options are being discussed for tackling the energy trilemma in the context of the energy transition. An overview is given in Table 1. A classification based on the main energy trilemma dimension that is targeted by each alternative is proposed. A subset of those options and the time horizons they apply to is illustrated in Figure 1. More details are given in the following section.

As the electric system impacts society in many ways, power market design aim at reconciliating several different objectives. They are commonly expressed as the energy trilemma, where one tries to develop a sustainable, reliable and affordable power market. As hydropower is a renewable, dispatchable and usually low-cost resource, it can contribute to all three dimensions of the energy trilemma. However, the correct incentives must be in place within the market design.

Table 1. Power market design options organized according to the dimensions of the energy trilemma

Sustainability	Reliability	Affordability
Global policies and mechanisms **Carbon pricing, emission trading systems** **Emissions performance standards** **Subsidy for reduction of carbon emissions, coupled with output** **Variable renewables support and financing** **Contracts for Differences (CfDs)** **Power Purchase Agreements (PPAs)** **Retailers obligations** **Renewable Portfolio Standards (RPS)** **Renewable Energy Standards (RES)** **Feed-in premiums (FiPs)** **Feed-in tariffs (FiTs)** **Renewable Energy Certificates (RECs)** **Net-metering**	**Capacity** **Equivalent firm power auctions (with CfDs)** **Capacity payments** **Centralized/decentralized reliability options** **Strategic reserve** **Targeted tender** **Long-term prices for hydropower and nuclear** **Ancillary services** **Smaller minimum bid sizes** **Aggregation of resources** **Asymmetrical bids** **Passive balancing** **Flexible ramping products** **Frequency response** **Flexibility** **Flexibility enhancements to the capacity market** **Cap & floor** **Retailers obligations** **Flexibility contracts** **Coupling of intra-day and balancing markets** **Incentives for demand-side flexibility**	**Wholesale market design** **National/zonal/nodal pricing** **Continuous trading/auctions** **Balancing regions** **Pay-as-clear/bid** **Self-/central dispatch** **Gate closure/settlement periods** **New near-term forward markets** **Dual market/green power pool** **Single buyer model** **Grid optimization** **Locational signals for investments** **Locational imbalance pricing** **Reform of network access** **Local markets** **Flow-based market coupling/splitting** **Dynamic line rating** **Coordinated reserves** **Grid tariff design** **Retail market design** **Real-time pricing, volumetric or capacity tariffs** **Prosumer interface and incentives** **Local markets and energy sharing schemes** **Long-term contracts for consumers**

Figure 1. Power market design options organized according to applicable time horizon



4.1 Discussed market designs in Europe

4.1.1 Power Purchase Agreements (PPAs)

PPAs consist of bilateral long-term contracts between a renewable energy generator and a power purchaser (typically a utility or corporate buyer) for the sale and purchase of electricity. PPAs establish the terms, namely the price, volume, duration, and other contractual provisions, between the generator and purchaser. PPAs are often financial, meaning that there is not necessarily a physical transaction between the two contract parties (Jones, 2023).

PPAs provide income certainty to investors, price stability for consumers and market access to producers. However, the negotiation process can be complex and will favour the most professional party. Moreover, the contractual obligations offer little opportunity for flexibility. There are some new developments in the form of so-called hybrid PPAs that are time-varying or refer to energy balance on a higher granularity than yearly. This could be interesting for storage assets, namely when co-located with a wind or solar power generator at a hybrid power plant (Rankin, 2023). Gabrielli et al. (2023) suggest a "proxy storage PPA" where cash flows would be determined by calculating the optimal arbitrage operations on the day-ahead market.

4.1.2 Contracts for Differences (CfDs)

Especially in Europe, CfDs can be seen as a special type of PPAs in which the purchaser is a public entity.[1] In the basic version, long-term central contracts (around 10-20 years) guarantee a strike price to generators for their entire production. Contracts are awarded through a competitive auction, which also sets the strike price. Whenever the market price is lower than the reference strike price (the contract price), the generator receives the difference as a top-up payment. Some variants are also suggested. For example, a strike range can be used instead of a strike price to enable market exposure, or the reference price can be set on a weekly horizon. The payment can also be

[1] In other parts of the world, for example in North America, PPAs can also be public if the buyer is a regulated utility.

decoupled from output through a cap & floor mechanism or by being based on the potential to generate rather than on the actual generation (Canestrini, 2023).

CfDs provide income certainty to investors and price stability for consumers. However, the basic version offers limited market exposure. Variants like the one suggested in (Newbery, 2021) can enable some market exposure, but market distortions remain. Access to this kind of mechanism could also be difficult for smaller consumers, and it will remove price elasticity and liquidity from the wholesale power market.

4.1.3 Pay-as-bid (vs pay-as-clear)

The pay-as-clear mechanism sets a uniform price for all actors at the highest accepted bid for clearing the market. The pay-as-bid mechanism pays each producer a price corresponding to their bid.

Although a pay-as-bid mechanism could prevent power producers from reaping windfall profits if bids were truly based on costs, real-life implementation is not promising. There is a high risk of market power abuse, inefficiency and lack of transparency. Lack of transparency would be especially challenging for hydropower producers who base their scheduling on a water value that is defined by expected inflow and expected prices. More variability and difficulty in forecasting market prices might reduce the efficient use of this resource (Tierney et al., 2008).

4.1.4 Dual market, or green power pool

The dual market would split the market into two settlements: prices in the variable, ‘as available’ market would be set by the long-run marginal cost of renewables through long-term contracts; prices in the firm, ‘on demand’ market would continue to be set by short-run marginal cost. Investment costs in the ‘as available’ market would be recovered by considering the long-run marginal cost in the contracts, while producers in the ‘on demand’ market would continue to recover their investment costs at times when they are inframarginal.

The green power pool would rely on the same concept but would work voluntarily.

This design might lead to clearer and more stable price signals while promoting access to low costs of renewables. However, it would increase complexity, require more coordination and decrease competition with market volumes and liquidity being split between two or more markets. Furthermore, in which of the settlements should hydropower be included? Would there be a distinction between run-of-river and reservoir hydropower, and if so, how? What about cascading hydropower plants? In (Grubb et al., 2022) it is suggested that large reservoir hydropower and other large-scale storage facilities would be in the ‘on demand’ market. However, details on the qualification criteria and the implementation remain to be specified. An alternative to the proposed two-market solution is the certificate system developed in the Nordic countries for reaching the obligation for 26,4 TWh windpower in the power system creating additional incentives for certain renewable technologies. (Linnerud and Simonsen, 2017)

4.1.5 Addition of near-term forward markets

New trading platforms or mechanisms allowing participants to buy and sell electricity contracts for delivery periods shorter than a few months would be introduced. The near-term forward markets would focus on shorter time intervals and higher granularity.

These additional forward markets could enhance price discovery and improve risk management, but a potential challenge is the risk of low liquidity.

4.1.6 Nodal pricing, or locational marginal pricing (LMP)

Nodal pricing is a pricing mechanism where electricity prices vary node by node in the power system according to transmission constraints and energy losses. This approach contrasts with zonal pricing, where a unique value for the electricity price is assigned to a large area as in the Nordic market today. While nodal pricing has been implemented in many regions in the US, zonal pricing remains the main principle in Europe, where transmission constraints are managed through redispatch. Even if nodal pricing is considered compatible with the Target Electricity Market (TEM) in the EU, it is not widely utilized across Europe (Newbery et al., 2018). When managing congestion between zones, the approach to calculating cross-zonal capacity can have a big impact. Traditionally, the net transfer capacity method (NTC) was used. It is simple but tends to underestimate available capacities, resulting in underutilization of resources. A more complex but also more accurate technique is the flow-based approach. Flow-based market clearing is already implemented in continental Europe, but implementation in the Nordic power market is planned for fall 2024 (Nordic RCC, 2023).

Nevertheless, Newbery et al. (2018) deplore the inadequacy of current short-run electricity prices in the EU for valuing flexibility, the lack of coupling in balancing markets, and the poor pricing of ancillary services. They consider that adopting nodal pricing would benefit Europe by reflecting the locational value of renewables and demand, hence incentivizing geographical diversification in investments and reducing inefficiencies in the current VRE support design. They argue that this would lead to large welfare gains in a future high-renewable energy system through better network use, cost savings, and improved price signals for supply and demand.

However, nodal pricing might be more efficient for short-term dispatch than for correct incentivization of investments, as increased volatility drives the cost of capital up. It also reduces liquidity and increases the possibility of local market power while at the same time raising fairness questions. Exposing only generators and larger loads to LMP could be an option for dealing with such distributional issues (Pollitt, 2023).

Implementing locational marginal pricing is also costly and technically challenging. Therefore, other alternatives are being assessed on how they can lead to similar outcomes. For example, support payments to flexible resources could constitute an interesting but less efficient alternative (Rintamäki et al., 2016).

4.2 Market design for capacity

The following market alternatives are aimed at maintaining capacity adequacy in the power system. The concepts and their description have been taken from the consultation document DEP2022-0612 “Review of Electricity Market Arrangements” from the UK government's Department for Business, Energy and Industrial Strategy. This document provides a good overview of power market design alternatives and will be referred to as the “UK REMA consultation document”.

4.2.1 Capacity payments

The capacity payment mechanism is a system that compensates power generators for maintaining and making available, when needed, a certain amount of electrical capacity to the grid. The amount of capacity needed for a definite time period is determined a few years in advance, based on a centrally determined reliability criterion. Depending on the electricity market, system operators or retailers can contract directly with generators or meet their capacity obligations through an auction (Botterud et Auer, 2020). The price (expressed as currency per megawatt-year) is set by the market clearing based on the generators’ bids. Therefore, the payment fluctuates over time and applies to all available capacities during each trading period. If the paid generators cannot provide energy when required, at a moment and for a duration specified in the contract or at the auction, they get a high penalty (Joskow, 2008).

While this mechanism is straightforward and can serve as a supplemental revenue source, notably for hydropower, its cost-effectiveness is limited due to the potential for overpayment, sometimes supporting capacity that is not really needed.

4.2.2 Centralized and decentralized reliability options

As explained in (Bhagwat & Meeus, 2019), reliability options are call option contracts for capacity. The TSO (in the centralized alternative) or retailers (in the decentralized alternative) determine the amount of capacity to be auctioned and, in return for a reliability premium (i.e. the price of these option contracts), secure the right to buy electricity from the assets on the wholesale market at a strike price. Contract-holding generators are strongly penalized if they are unavailable when the real-time price exceeds the strike price. Indeed, they lose a high-revenue opportunity while having to buy back the capacity on the market at a high price. Contrary to capacity payments that are added to wholesale market revenues, reliability options cap revenues (at the strike price) and compensate with the reliability premium.

This mechanism provides price stability through a price cap and support for investment through rent. The UK REMA consultation document prefers the centralized format over the decentralized one. In a decentralized reliability options setting, the penalty that the retailers would have to pay if they under-procure might be hard to set to reach the desired security of the supply level. Moreover, the additional costs incurred to the retailers could be passed on to the consumers, raising fairness issues.

4.2.3 Targeted tender

A central authority defines the amount of new capacity to procure through new investments. These tenders can be customized to fulfil particular specifications or criteria. An example is the Spanish call for new energy storage, including pumped storage, as discussed in section 3.2.3.

This mechanism can support specific policy goals and be adapted to specific needs. This tailoring has a flip side of limited competition and low cost-effectiveness, given the risk of overpayment, or underpayment and a lower reliability if the flexibility needs are underestimated.

4.2.4 Strategic reserves

An auction for a specific quantity of reserve capacity is conducted by a central authority, possibly with additional requirements. This capacity supplements what the market offers and is to be utilized only if the market fails to clear. Compensation for selected generators follows a pay-as-bid and is typically divided between payment for availability and payment for activation.

This design can possibly lead to lower costs than a capacity market while maintaining price stability. From a hydropower perspective, it has the advantage of possibly incentivizing long-duration storage capacity. On the other hand, there is a risk of underutilization of resources, to an extent, depending on whether the reserves can qualify as power and energy reserves simultaneously. If hydropower is saved for too long, it might lead to an increased risk of spillage, reducing wholesale income and indicating suboptimal use of the flexible resource. Limited effectiveness because of time, grid bottlenecks and other locational constraints could also be a risk.

4.3 Market design for flexibility

The following options are aimed at ensuring sufficient flexibility in the power system. Apart from flexibility contracts, the concepts and their description have been taken from the UK REMA consultation document.

Here, market design for flexibility refers to regulated insurance mechanisms for consumers and producers, supporting operations or investments.

4.3.1 Flexibility enhancements to the capacity market

Flexibility characteristics targeted by flexibility enhancements to the capacity market could include response time, duration, and location. Auctions for those characteristics could be added to remunerate services enabling adjustment in the power balance to incentivize investment in resources to provide such services. They could be open to all technologies or limited to low-carbon ones, based on criteria to be specified. Another possibility would be to apply multipliers valuing flexibility characteristics, such as ramping abilities, to the capacity clearing price. This way, assets that have those characteristics would receive a bonus to their capacity remuneration. Separate auctions and multiple clearing prices are also considered.

These enhancements would preserve continuity with the present market design while enabling the targeting of specific characteristics. This could be especially relevant for incentivizing long-duration storage. However, these modifications would add complexity and reduce predictability. There is also a risk of miscalibration of the incentive parameters, and liquidity could be reduced if generic auctions become subdivided into specific ones.

An example of how difficult it is to correctly incentivize flexibility is the 10 MW limit in the definition of "small hydro" (NVE, 2024) which simultaneously works as a limit for adding flexibility to the hydropower system. From a long-term perspective and given the large shift in the clean energy transition, it could have been more favourable to the power system to increase flexibility rather than aiming for an economic constraint (apparently arbitrarily) supporting smaller power plants. For example, why would 10 MW be good if 15 MW is not?

4.3.2 Cap & floor

The government guarantees a minimum revenue, or floor, over a predefined time horizon to selected flexible generators. In return, a maximum revenue, or cap, is agreed upon to prevent excessive profits. A soft cap should be preferred to preserve high price signals. Those bounds would be determined based on the generation capacity of the asset.

This mechanism would provide income certainty for investors while limiting excessive profits but at the same time weakens the market signals. This last effect could be partly mitigated by implementing a soft cap rather than a hard one, where higher profits are taxed at a higher rate and where windfall profits are redistributed in other ways.

4.3.3 Retailer obligations (market-based)

Retailer obligations for flexibility consist of legal mandates on retailers to attain a centrally defined target in terms of flexibility services. It is a decentralized mechanism as the market is used to trade those services in order to comply with the obligations.

This obligation would strengthen investment and operational signals for flexibility while enabling competition across technologies if the rules comply with all technologies. However, this kind of design presents risks in financing and delivery and can lead to income uncertainty for large flexible assets. Setting the same obligation to all retailers everywhere might be more expensive than adding extra flexibility where it is cheap and none where it is expensive. Indeed, adding too strict requirements tends to reduce liquidity, leading to suboptimality.

4.3.4 Flexibility contracts

Flexibility contracts (Fabra, 2022) would consist of a CfD with a sliding premium for price exposure. The payments are coupled with output and correspond to the strike price, set through auctions, in addition to the differential between the market price and the reference price. Here, the type of flexibility that is remunerated is the ability to follow wholesale price signals. Penalties for withholding can be included.

Such contracts would provide income certainty to investors while preserving some level of market exposure and price stability for consumers. These advantages would be achieved at the expense of weakened price signals, high transaction costs and an increased risk of market power.

4.4 Market design for ancillary services

Here, market design for ancillary services refers to mechanisms applying to the real-time market and preserving the stability of the grid. In other words, the targeted time horizon is shorter than in the previous section. The presented alternatives come from the TradeRES project (Morales-España et al., 2021).

4.4.1 Flexible ramping products

The aim is to ensure enough ramping capacity (up and down) is available in real time. The price and procurement are determined based on demand curves, which are calculated from historical forecast errors. Historically this is given by the unavailability of large units or grid connections with some impact from load-forecast errors. These historical forecast errors cannot be expected to be sufficient in support of the energy transition where both RES variation and demand response will be key components for defining the flexibility need. As more interconnections are built between the Nordics and the Central European system, many of them of high-voltage direct-current (HVDC) type, ramping restrictions on interconnections have become a major discussion topic as well (Statnett, 2020).

Remunerating flexible ramping would incentivize enhanced supply and potentially be beneficial for flexible hydro, but the valuation and estimation of the needed volume of the service is complex to perform.

4.4.2 Frequency response incentives

Frequency response consists of power being injected into (or absorbed from) the grid in response to changes in observed frequency as a way to mitigate the deviation after an unexpected disturbance or imbalance occurs.

Similar to ramping products, remunerating frequency response would incentivize enhanced supply from hydropower, but the valuation of the service is complex to perform.

5 Conclusion

5.1 Key takeaways

Power market design creates conflicts between and within dimensions of the energy trilemma. For example,

- income certainty for investors and price stability for consumers is often obtained at the expense of market efficiency.

- trying to establish clear requirements for power grid needs in order to fulfil them tends to compromise market liquidity and competition.

- market mechanisms that aim for simplicity and transparency, like capacity payments, can compromise cost efficiency.

In general, in Europe, forward markets require improvements, but the short-term markets function well. Nevertheless, on all time horizons, various constraints and failures in wholesale markets create a need for complementary markets. For example, CfDs and PPAs could be valuable tools for VRE development, but such remuneration mechanisms outside the market add complexity, and impacts on flexible generation must be investigated. More generally, capacity, flexibility, storage and ancillary services are all paramount to the energy transition. Hydropower can contribute to their provision. Adequate remuneration for all these services must be ensured to achieve reliable, sustainable and affordable future power systems, which are key targets of European policies.

5.2 Further work

This report shows the increasing research effort that goes into the field of power market regulations that can facilitate the clean energy transition. This section points to areas that are so far little researched and where new knowledge is needed to back up informed decisions about changes to the power system regulation.

Current publications show adaptations and adjustments to the current regulation and market solutions. What is so far missing is the perspective of what is needed if the power system is going to reach deep decarbonization in a cost-efficient manner. Is it adequate to consider minor adjustments, or do we need to rethink the operation of the market along with other changes in society?

One example is the mechanisms that now define the volumes of flexibility needed in relation to frequency regulation. More and more of the equipment in the power system is less sensitive to frequency variation, so it becomes a question of how much fast reserves are actually needed in the future power system if current frequency management constraints can be relaxed (Hamzah Ahmed, 2023). In this light, technical and economic consequences for the power market regulation should be investigated.

Increased understanding of the local versus global regulation consequences is another example. As energy communities are established and consumer empowerment is nourished, sub-optimal solutions may increase not only the cost of the energy transition but also the cost of the day-to-day operation needed to maintain a stable power system.

The impact on hydropower from the new European market reform needs to be investigated and analysed. The market reform is not concrete on actual measures and is currently being implemented. What we see from Spain is the first actual actions based on the new reform. Although they are early and perhaps not fully compliant, it will be important for Norway to follow up. We have to understand the actual impacts of new power market design and implement the possibilities for value creation that it gives.

These questions are best addressed by simulating how the power system and its actors will respond to the proposed market designs. This implies increasing the modelling capabilities of power market models to investigate future operations and the impact of changed regulations on the power system. The above examples both call for new mechanisms when modelling the price formation in power markets, such as energy storage, and technical constraints for modelling flexibility but also to manage strategic behaviour, which is an important aspect of the European REMIT regulation. A more comprehensive discussion about the modelling challenge can be found in (Haugen et al., 2023).

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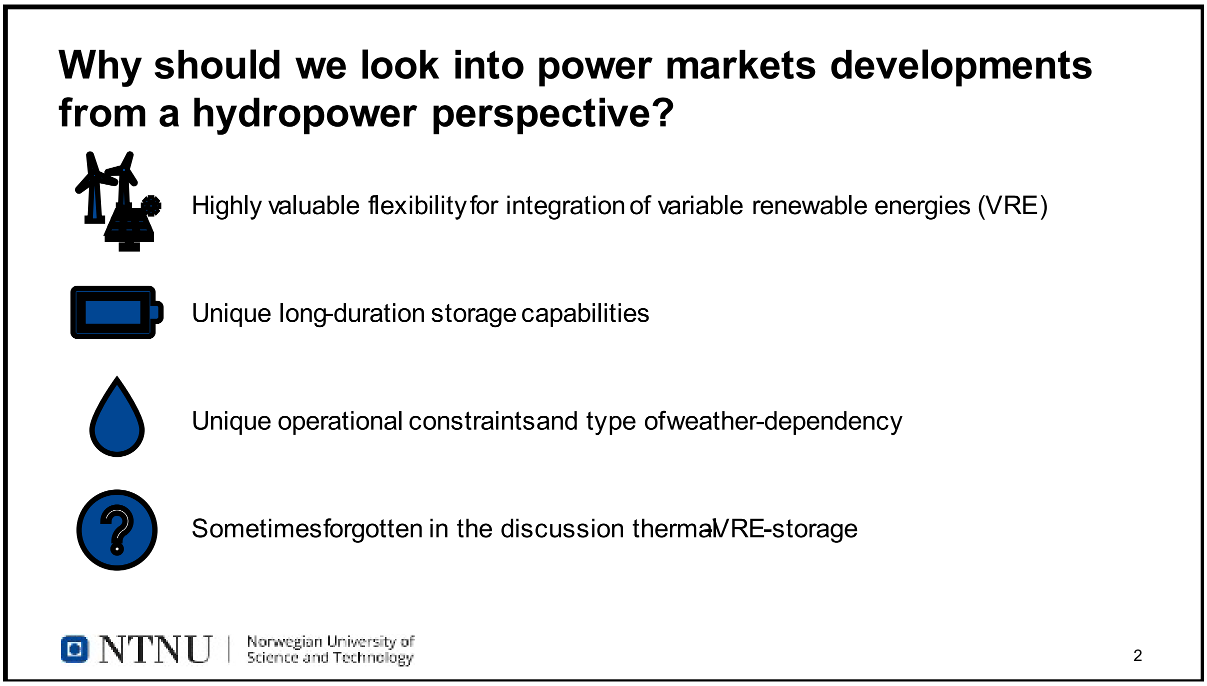
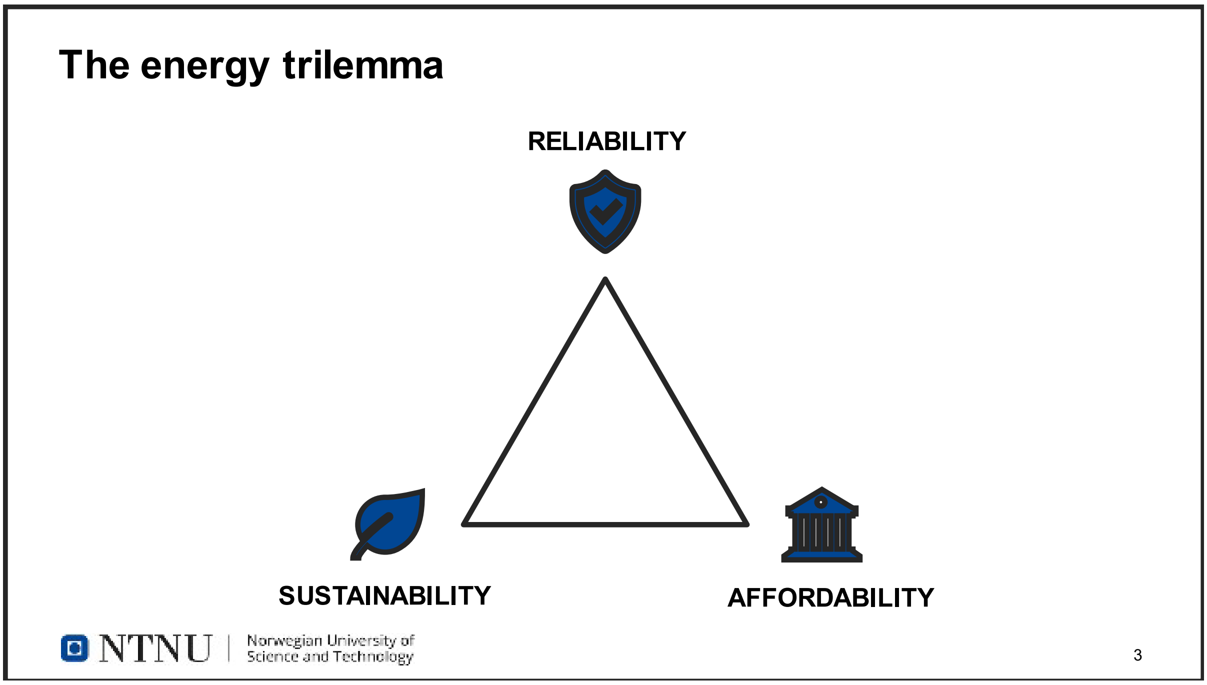
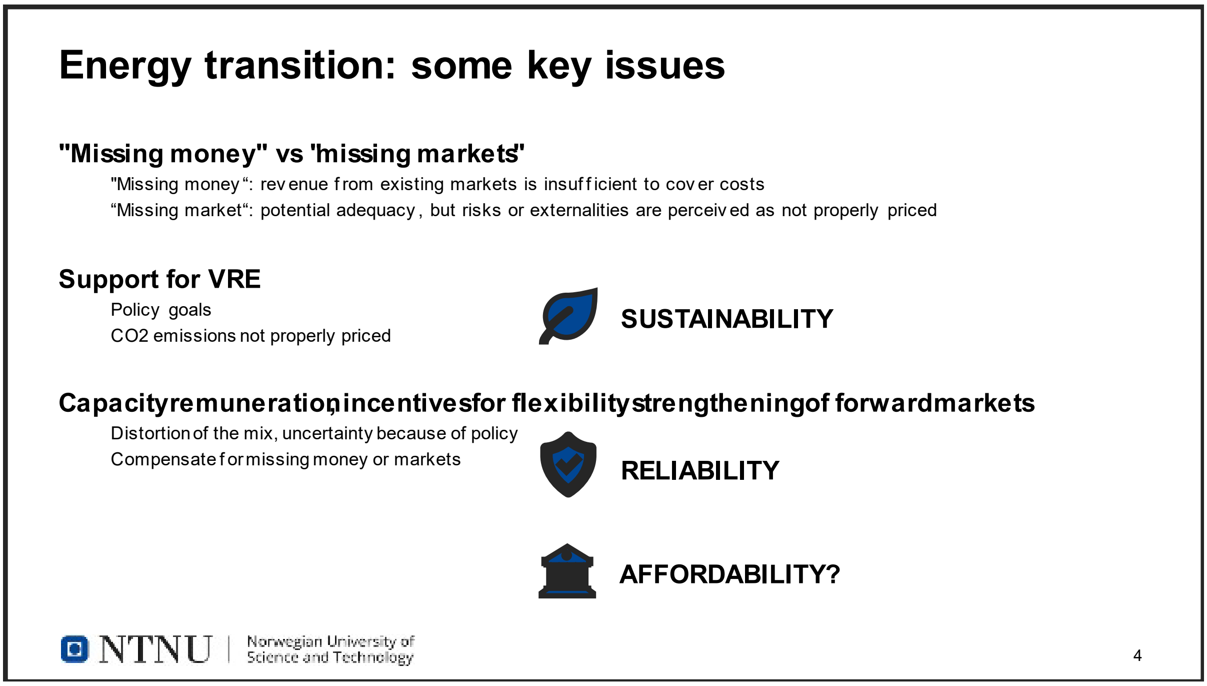
7 Appendix

Final presentation of the HydroFy project




The energy trilemma
RELIABILITY
SUSTAINABILITY
AFFORDABILITY
NTNU | Norwegian University of Science and Technology
3


Energy transition: some key issues
"Missing money" vs 'missing markets'
"Missing money": revenue from existing markets is insufficient to cover costs
"Missing market": potential adequacy, but risks or externalities are perceived as not properly priced
Support for VRE
Policy goals
CO2 emissions not properly priced
SUSTAINABILITY
Capacity remuneration, incentives for flexibility strengthening of forward markets
Distortion of the mix, uncertainty because of policy
Compensate for missing money or markets
RELIABILITY
AFFORDABILITY?
NTNU | Norwegian University of Science and Technology
4

Response to the 2022 energy crisis

An unprecedented crisis

High prices for consumers, high windfall profits for producers

Questioning of power market design

Price caps, windfall taxes, subsidies to thermal generators?
Splitting the market between «on-demand» / «as-available»?
Pay-as-bid? Remuneration based on average costs?

A natural gas crisis

Need for improved risk hedging, both on consumers' and producers' side
Long-term contracts (PPA, CfD)
Affordability options (Battle et al., 2022)

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Power market design: key considerations for hydro

Services that hydro can provide – key words

Capacity
Ancillary services
Flexibility
Storage (depending on the definition)

Special features related to hydro

Annual variability in generation
Different levels of dispatchability (from run-of-river to big reservoirs)

A stochastic resource that can help with reliability

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Several market design options can be considered for tackling the energy trilemma.

SUSTAINABILITY	RELIABILITY	AFFORDABILITY
Global policies and mechanisms	Capacity	Wholesale market design
Variable renewables support and financing	Ancillary services	Grid optimization
	Flexibility	Retail market design

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Several market design options can be considered for tackling the energy trilemma.

SUSTAINABILITY

Global policies and mechanisms
- Carbon pricing, emission trading systems
- Emissions performance standards
- Subsidy for reduction of carbon emissions, coupled with output

Intermittent renewables support and financing
- Contracts for Differences (CfDs)
- Power Purchase Agreements (PPAs)
- Suppliers obligations
- Renewable Portfolio Standards (RPS), Renewable Energy Standards (RES)
- Feed-in premiums (FiPs)
- Feed-in tariffs (FiTs)
- Renewable Energy Certificates (RECs)
- Net-metering

☐ ***Hot topics***
☐ ***Focus on hydro***

RELIABILITY

Capacity
- Equivalent firm power auctions (with CfDs)
- Capacity payments
- Centralized/decentralized reliability options
- Strategic reserve
- Targeted tender

Ancillary services
- Smaller minimum bid sizes
- Aggregation of resources
- Asymmetrical bids
- Passive balancing
- Flexible ramping products
- Frequency response

Flexibility
- Flexibility enhancements to the capacity market
- Cap & floor
- Suppliers obligations
- Flexibility contracts
- Coupling of intra-day and balancing markets
- (Long-term prices for hydropower and nuclear)

AFFORDABILITY

Wholesale market design
- National/zonal/nodal pricing
- Continuous trading/auctions
- Balancing regions
- Pay-as-clear/bid
- Self-/central dispatch
- Gate closure/settlement periods
- Addition of near-term forward markets
- Dual market/green power pool
- Single buyer model

Grid optimization
- Locational signals for investments
- Locational imbalance pricing
- Reform of network access
- Local markets
- Flow-based market coupling/splitting
- Dynamic line rating
- Coordinated reserves

Retail market design
- Real-time pricing, volumetric or capacity tariffs
- Prosumer interface and incentives
- Local markets and energy sharing schemes

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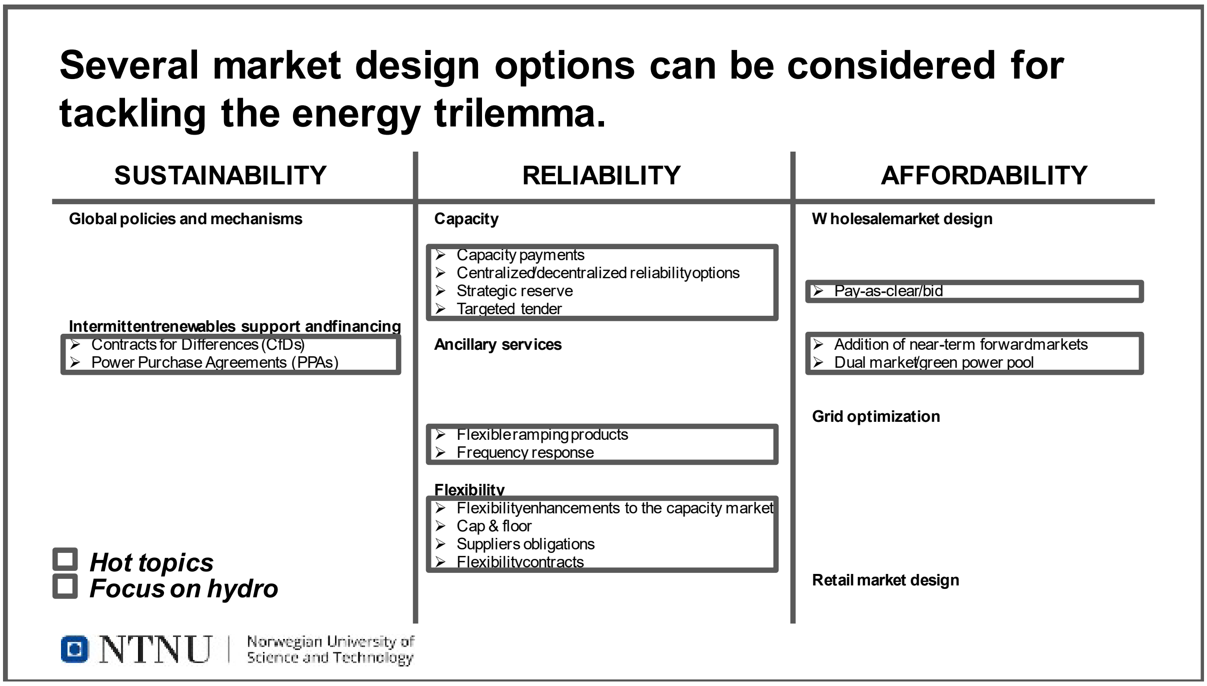
Several market design options can be considered for tackling the energy trilemma.
SUSTAINABILITY
RELIABILITY
AFFORDABILITY
Global policies and mechanisms
Intermittentrenewables support andfinancing
Contracts for Differences (CfDs)
Power Purchase Agreements (PPAs)
Capacity
Capacity payments
Centralized/decentralized reliabilityoptions
Strategic reserve
Targeted tender
Ancillary services
Flexibleramping products
Frequency response
Flexibility
Flexibilityenhancements to the capacity market
Cap & floor
Suppliers obligations
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W holesalemarket design
Pay-as-clear/bid
Addition of near-term forwardmarkets
Dual market/green power pool
Grid optimization
Retail market design
Hot topics
Focus on hydro
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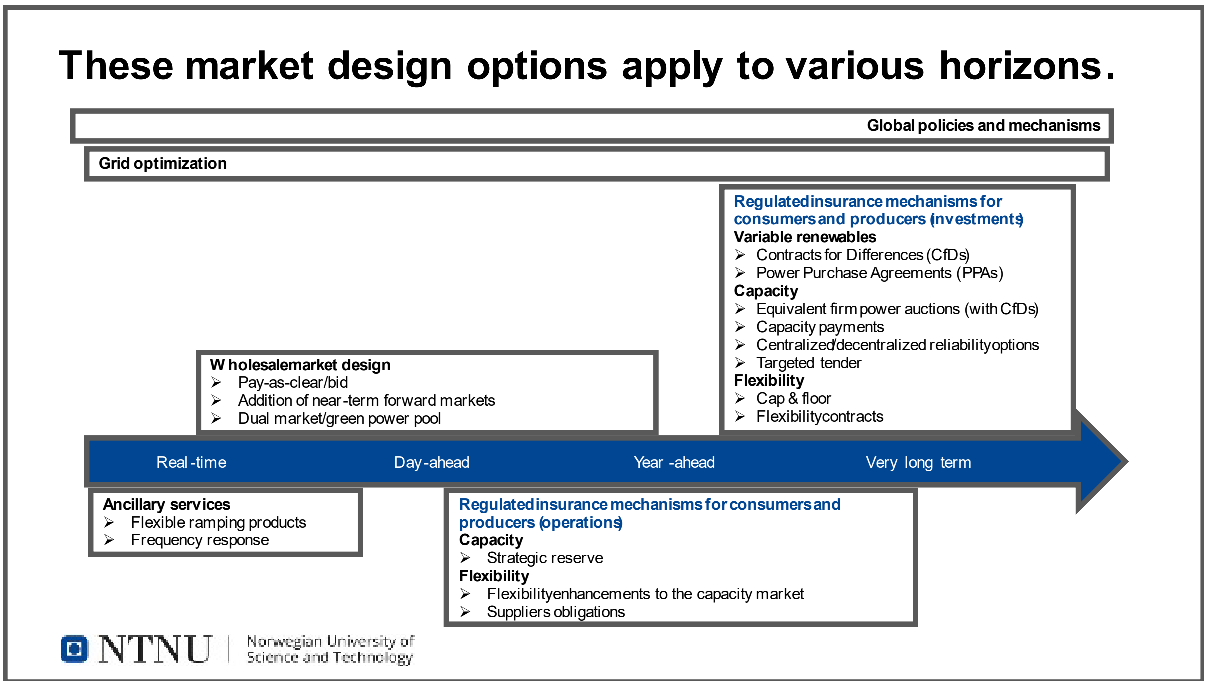
These market design options apply to various horizons.
Global policies and mechanisms
Grid optimization
Regulatedinsurance mechanisms for consumersand producers (investments)
Variable renewables
Contracts for Differences (CfDs)
Power Purchase Agreements (PPAs)
Capacity
Equivalent firm power auctions (with CfDs)
Capacity payments
Centralized/decentralized reliabilityoptions
Targeted tender
Flexibility
Cap & floor
Flexibilitycontracts
W holesalemarket design
Pay-as-clear/bid
Addition of near-term forward markets
Dual market/green power pool
Real-time
Day-ahead
Year -ahead
Very long term
Ancillary services
Flexible ramping products
Frequency response
Regulatedinsurance mechanisms forconsumersand producers (operations)
Capacity
Strategic reserve
Flexibility
Flexibilityenhancements to the capacity market
Suppliers obligations
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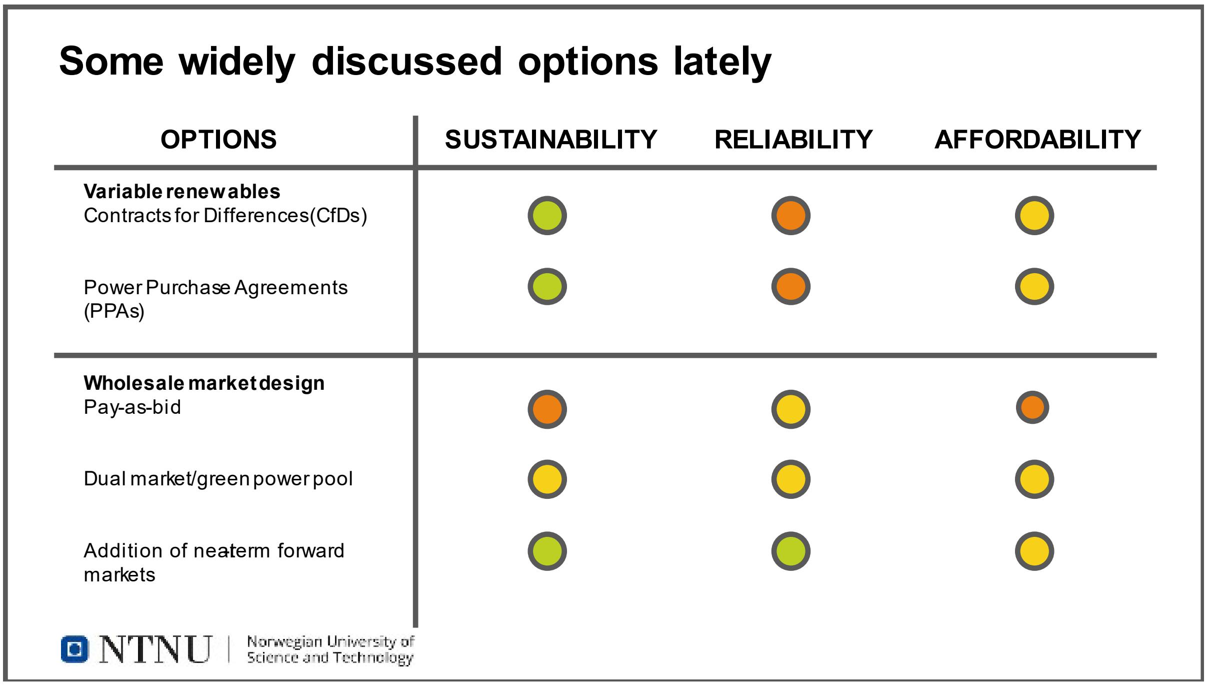
Some widely discussed options lately
OPTIONS
SUSTAINABILITY
RELIABILITY
AFFORDABILITY
Variable renewables
Contracts for Differences (CfDs)
Power Purchase Agreements (PPAs)
Wholesale market design
Pay-as-bid
Dual market/green power pool
Addition of near-term forward markets
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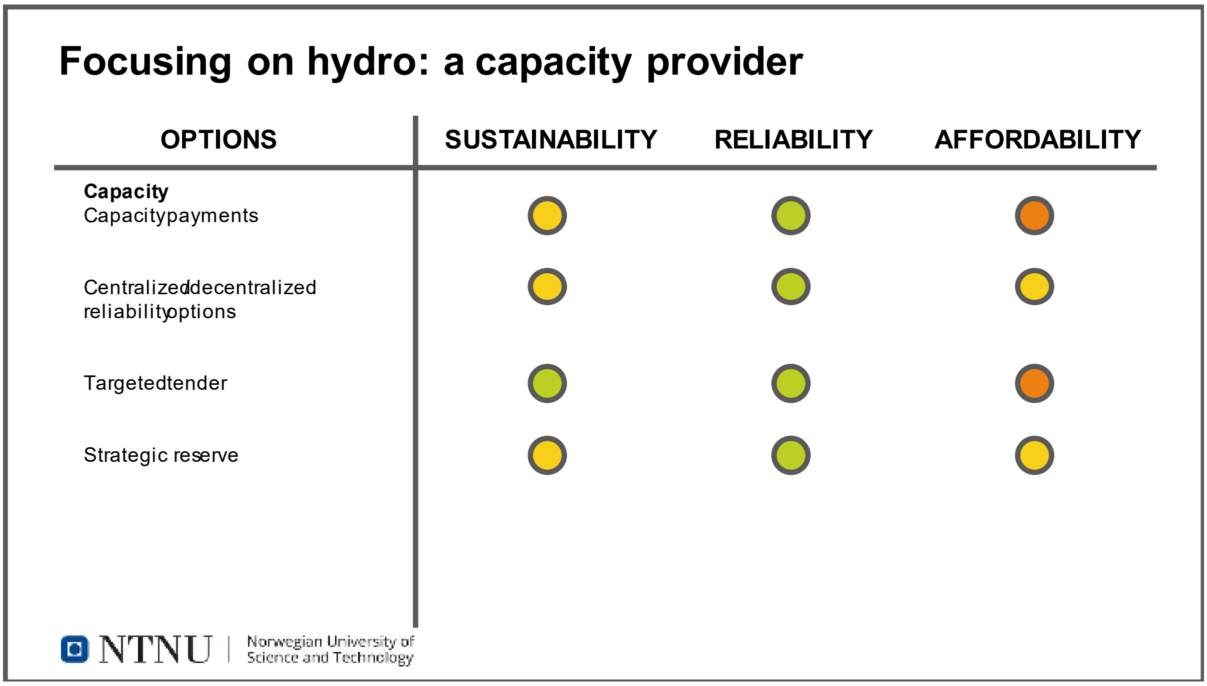
Focusing on hydro: a capacity provider
OPTIONS
SUSTAINABILITY
RELIABILITY
AFFORDABILITY
Capacity
Capacity payments
Centralized/decentralized reliability options
Targeted tender
Strategic reserve
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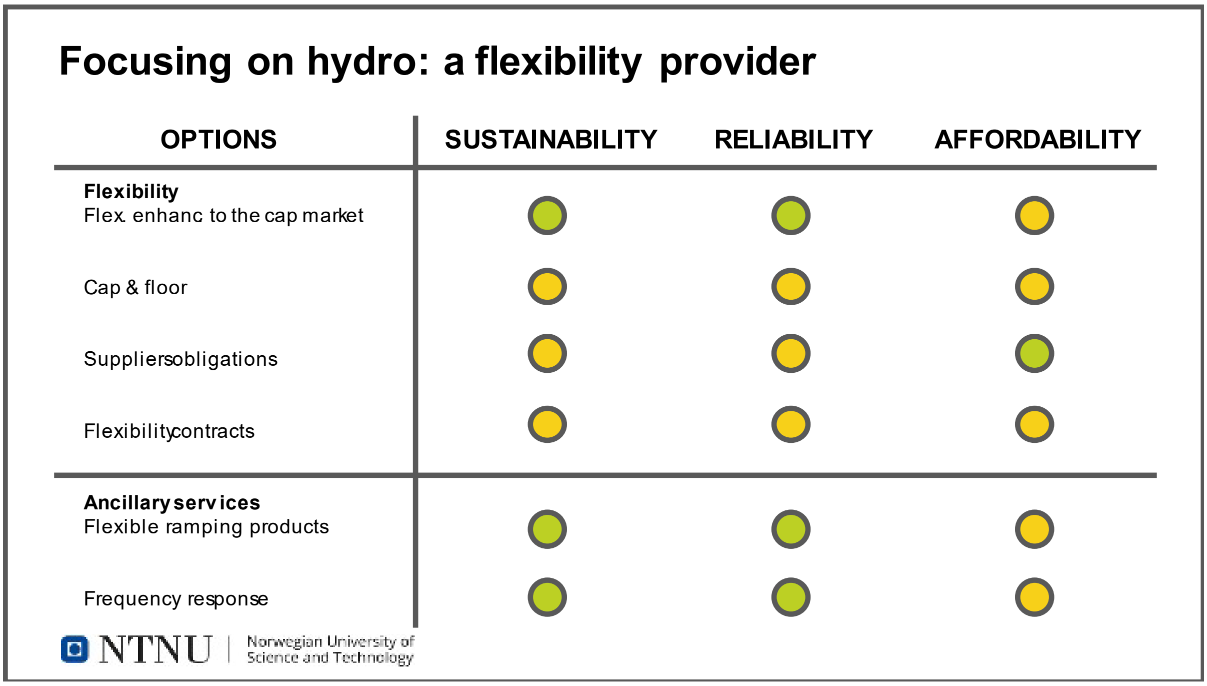

Key Takeaways

Conflicts between and within dimensions of the **energy trilemma**

- Income certainty for investors and price stability for consumers VS market efficiency
- Clear requirements for power grid needs VS market liquidity and competition
- Design simplicity VS cost-efficiency
- **Hydropower**: exploiting its full generation and flexibility potential VS preserving the local environment

Well-functioning short-term market, **improvements** to be made to **forward markets**

CfDs and PPAs could be **valuable tools for VRE** development, but remuneration mechanisms outside the market increase the **need for a more complex market**, and **impacts on flexible generation** must be investigated

Various **constraints** and **failures** in wholesale markets create a **need for complementary markets**

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HYDROFY PROJECT:
RECENT DEVELOPMENTS IN POWER MARKET DESIGN – FOCUSING ON HYDROPOWER

Final report to be finished before end of 2023,
to be shared in early 2024

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Thank you for your attention!

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ISSN:_2535-5392
ISBN: 978-82-93602-43-9

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