FINAL REPORT

# THE ORDER OF TRANSFORMATION

# SECURITY OF SUPPLY IN THE ELECTRICITY MARKET

Study commissioned by

BNE Bundesverband neue Energiewirtschaft e. V.
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Original German version: July 9, 2024

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## SECURITY OF SUPPLY IN THE ELECTRICITY MARKET

Final report original German version, July 9, 2024

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"One moment, please. Forget all these complicated economic theories. We've spent the whole day driving around London, and there's one thing I simply don't understand. Back home in Moscow, our finest minds are working on the bread supply system, and yet there are always endless queues at every bakery and grocery store. Here in London, live millions of people, and we've passed many shops and supermarkets today, but I haven’t seen anyone queuing for bread. Please take me to the person who is responsible for the bread supply in London. I must learn their secret."

This quote from Yuval Noah Harari's book "Homo Deus" describes the visit of a close associate of Gorbachev, who was tasked with understanding "Thatcherism" in London in the 1980s.

Commissioned by:

Background

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# List of Abbreviations

| | |
|---|---|
| a | Year |
| BMWK | Federal Ministry for Economic Affairs and Climate Action |
| CCS | Carbon Capture and Storage |
| CfD | Contract for Difference |
| $CO_2$ | Carbon Dioxide |
| d | Day |
| DLM | Decentralised Capacity Market (Dezentraler Leistungsmarkt) |
| EEG | Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz) |
| EENS | Expected Energy Not Served |
| EnWG | Energy Industry Act |
| EPS | Emission Performance Standard |
| ETS | Emissions Trading System |
| EUR | Euro |
| g | Gram |
| GUD | Combined Cycle Gas Turbine (Gas-und-Dampf-Kraftwerk) |
| GT | Gas Turbine |
| GW | Gigawatt |
| h | Hour |
| $H_2$ | Hydrogen |
| KTF | Climate and Transformation Fund |
| kW | Kilowatt |
| kWh | Kilowatt-hour |

| | |
|---|---|
| KWS | Power Plant Strategy (Kraftwerksstrategie) |
| MSR | Market Stability Reserve |
| $MWh_{th}$ | Megawatt-hour thermal |
| $MWh_{el}$ | Megawatt-hour electric |
| LOLE | Loss of Load Expectation |
| PPA | Power Purchase Agreement |
| RE | Renewable Energy/Electricity |
| RES | Renewable Energy Sources |
| UCPTE | Union pour la coordination de la production et du transport de l'électricité |
| UCTE | Union for the Co-ordination of Transmission of Electricity |
| VSN | Reliability Standard Certificates (Versorgungssicherheitsnachweise) |

Disclaimer

This study is intended as a contribution to the ongoing discussion on the further development of electricity market design. It should not be understood as a personal critique of any stakeholders involved in the debate, but rather as part of a joint effort to identify the best possible solutions. We assume that all parties are acting with the best of intentions and hope that this study will support a better understanding and more informed decision-making.

CONNECT

# THE ORDER OF TRANSFORMATION

## Executive Summary

*If it were possible to anticipate and model the complexity of reality and future developments, we would not need the exploratory processes of markets – we could simply plan the ideal future centrally.*

### How Can Security of Supply Be Ensured Most Effectively in the Electricity Market?

The current debate focuses primarily on how best to promote the construction of new power plants. Underlying this discussion is the notion that security of supply can only be achieved through the direct subsidisation of power plants. This study seeks to broaden the scope of solutions and arrives at the conclusion: The electricity market can be improved in a way that strengthens the market-based organisation of security of supply and provides more cost-efficient investment incentives for the required capacity.

Specifically, the study finds: An obligation to hedge is more suitable for the German electricity market than a capacity mechanism. A hedging obligation means that suppliers must hedge their supply commitments in the long-term markets. It is already part of the European requirements set out in the Electricity Market Directive and must be implemented in any case.

### Why Is the Hedging Obligation Superior to Capacity Markets?

A targeted implementation of the hedging obligation, as stipulated by the recent reform of the European Electricity Market Directive, offers the appropriate foundation for further developing the market design. It represents the more cost-efficient and more robust measure to ensure security of supply – while also requiring the least implementation effort. From a European legal perspective, it is also positively assessed, as it strengthens the internal market and has the legal advantage of being rapidly implementable. The hedging obligation constitutes an evolution of existing rules and can therefore be introduced more swiftly than a potentially error-prone reorganisation of security-of-supply mechanisms.

- Suppliers that do not hedge their supply obligations in the long-term markets currently create a negative risk externality – as became evident during the energy crisis through insolvencies and the obligation of default supply. This free-rider behaviour results in insufficient long-term hedging of supply obligations in the long-term markets. The hedging obligation corrects this by internalising this risk externality.
- Investors currently face limited incentives to invest in dispatchable capacity. A hedging obligation accounts for the need for dispatchable resources, making the value of security of supply more visible in long-term market prices.
- Consumers can determine, based on their historical consumption patterns, how much capacity they want to hedge through their supplier. In doing so, a key weakness in the current market design is addressed: consumers can signal their willingness to pay for a secure electricity supply through their price-elastic consumption behaviour.
- Investors benefit from economically sound investment signals based on consumers' willingness to pay. The need for regulatory intervention due to inelastic demand is eliminated. As a result, the risk of a permanent regulatory spiral is reduced, along with the uncertainty about future changes to the regulatory framework.
- The hedging obligation also incentivises the flexibilisation of the electricity system and allows market participants to decide which technologies are most suitable. In this way, the market can simultaneously ensure security of supply and efficiently integrate renewable energy. As a result, total system costs are significantly lower than under capacity markets. Moreover, there is no need for financing via the public budget or a new levy.

Capacity markets, by contrast, create distorted incentives, externalities, and a need for permanent political readjustment through regulatory micromanagement. Moreover, investment reluctance is likely to persist until all detailed rules have been finalised.

- SELECTIVE MECHANISMS: As the debates surrounding the Power Plant Strategy (KWS) illustrate, selective capacity mechanisms that promote only specific technologies are subject to political uncertainty and vulnerable to interest-driven influence (rent seeking). They crowd out other – especially innovative – technologies and therefore distort competition, including in the internal market. Furthermore, they create path dependencies that trigger further subsidies and regulatory interventions. Subsidising operational hydrogen-based power generation, for instance through hydrogen contracts for difference ($H_2$-CfDs), would displace flexibility options and other technologies. This would not only permanently increase total system costs but also create dependencies on a single fuel, thereby reducing security of supply.

- DECENTRALISED AND HYBRID CAPACITY MARKETS: Due to the various regulatory requirements involved, decentralised and hybrid capacity mechanisms tend to undergo political adjustments over time, leading them to increasingly resemble central capacity markets.
- CENTRALISED CAPACITY MARKETS: In order to balance market power mitigation with the need to incentivise investment, central capacity markets require a complex regulatory framework with numerous administratively defined parameters. Market-based allocation mechanisms are replaced by central decisions. As a result, administrative assumptions about the future determine the profitability of technologies within the market. This distorts competition both within the internal market and among (innovative) technologies. The design criteria are inevitably based on the characteristics of conventional thermal power plants. Experience from the UK shows that, over the medium to long term, this can reduce the market opportunities for storage technologies, for example. This leads to a decline in power system flexibility, which in turn reduces the market value of wind and solar power and increases the need for subsidies. Ultimately, capacity markets create additional externalities, trigger a slippery slope of growing overcapacity, and increase total system costs.

Capacity support instruments are not suited to ensuring security of supply in a dynamic electricity market with a high penetration of renewable energy. Selecting individual technologies based on today's assumptions about the future, while displacing flexibility options and innovative solutions, creates path dependencies that result in permanently higher total system costs.

### What Else Should Be Done in Addition to the Introduction of the Hedging Obligation?

In addition to the introduction of the hedging obligation, the price signal should be strengthened in particular through the following additional measures:

- CRISIS MECHANISM: Even in times of crisis, it is beneficial for prices to continue being determined by the market so that market-based allocation mechanisms can remain effective. To ensure that decision-makers remain capable of taking action during such times, a mechanism is needed that can specifically address social and economic hardship – without intervening in price formation.
- INCREASING DEMAND ELASTICITY: Technical flexibility is a prerequisite for price elasticity, as it gives consumers the freedom to choose how they respond to price signals. The main benefit of price-elastic consumers therefore does not lie in their technical flexibility, but in their ability to signal their willingness to pay for a secure electricity supply. This enables reliable investment incentives. For household customers, a well-designed smart meter rollout and the rapid adoption of dynamic tariffs should be implemented. For larger consumers, a further development of the special network charges under § 19.2 StromNEV is recommended, while also safeguarding the competitiveness of the businesses concerned.
- DYNAMIC INCENTIVES FOR GRID USAGE: Limited transport capacity at all voltage levels generates costs through redispatch and interventions under § 14a EnWG, which are not borne by the originator but by society as a whole (external costs). Internalising these external costs by introducing time-differentiated incentives for grid usage – provided they do not undermine the competitiveness of businesses – can help reduce redispatch volumes and interventions under § 14a EnWG.
- CORRECTING REDISPATCH DISTORTIONS: In redispatch, part of the fixed costs (so-called asset depreciation costs) is reimbursed. This cost component is factored into bidding behaviour on the power market, making it less likely for grid-friendly plants to be dispatched in the market. As a result, grid congestion is exacerbated and these plants must be redispatched later. The positive externalities of grid-advantageous assets could instead be recognised via a feed-in premium, which would allow them to be more often dispatched in the market. Such premiums would also reward timely investments in grid-supportive locations.

A power market strengthened by the introduction of the hedging obligation – whose price signal will function even more effectively in the future – can reliably ensure security of supply. It does so more efficiently and effectively than a capacity market or a selective capacity mechanism. Moreover, it puts an end to investment reluctance (attentism) and can therefore trigger new investments more swiftly.

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# 1 Introduction

The current policy debate on the future of electricity market design is primarily centred on the question of how to support the construction of new power plants. This perspective implicitly assumes that there is no meaningful allocation task to be addressed through market-based discovery processes. Yet the real question, when it comes to ensuring a cost-efficient, environmentally sustainable and secure electricity supply, is: how can security of supply be guaranteed in the future?

This question opens up a broader solution space in which (hydrogen-based) gas-fired power plants will likely play a role – but they will not be the only part of the answer. A significant part of the solution is also likely to come from flexibility options and innovative technologies that would be sidelined if the debate focused solely on investment in generation capacity. After all, a key aspect of the allocation process is to determine the appropriate mix and volumes of technologies that can contribute to security of supply.

A sustainable market design must therefore also address the question of how to incentivise the right technologies, rather than assigning central authorities the responsibility to decide how much of which technology should be supported. In other words: market-based incentives are needed to tackle complex allocation challenges.

When approaching the reform of the market design from the perspective of security of supply and incentive mechanisms, a follow-up question arises: in what ways does the electricity market differ from other market-based systems? This study explores such questions on behalf of a consortium of stakeholders. We examine how the fundamental characteristics of the future power system are evolving, and what implications these developments have for the market-based organisation of security of supply.

In the past, the key challenge of the energy transition initially lay in the technological development of renewable energy sources, and increasingly in their integration into the market. In these early phases, it was still possible to rely on a well-developed and generously dimensioned generation and grid infrastructure. Looking ahead, the power system must be organised in a way that allows for the highest possible share of renewable electricity to be utilised, while ensuring that electricity demand can still be met reliably, climate-friendly, and at reasonable cost during periods of low renewable generation.

As a result, this study proposes a sustainable market design capable of integrating the core objectives of the energy policy triangle. The aim of this approach is to address the current challenges of the transition phase while providing a stable and predictable long-term framework for investors.

Following this introduction, Chapter 2 outlines the evolution of the electricity market to date and highlights the current challenges of the transformation. This includes a discussion of existing distorted incentives, uncertainties, and market imperfections. In Chapter 3, we develop a set of criteria for assessing future market design reforms – both for the transition phase and beyond. Chapter 4 provides the conceptual background for a more fundamental discussion on the added value of market-based coordination. It explores the specific requirements that the organisation of secure electricity supply must fulfil in order to reflect the objectives of the energy policy triangle. Building on this, Chapter 5 examines different capacity mechanisms and evaluates their suitability in the context of the German energy transition. In Chapter 6, we propose adjustments to the regulatory framework that could enable a market-based organisation of electricity supply. The study concludes in Chapter 7 with a summary and conclusion.

# 2 Current Situation and Motivation

INVESTMENT RELUCTANCE

The current reluctance to invest can primarily be attributed to distorted political-economic incentives and uncertainty.

In this chapter, we discuss the key challenges of the current transformation phase towards a climate-neutral power system. We also reflect on past developments that have contributed to the present situation.

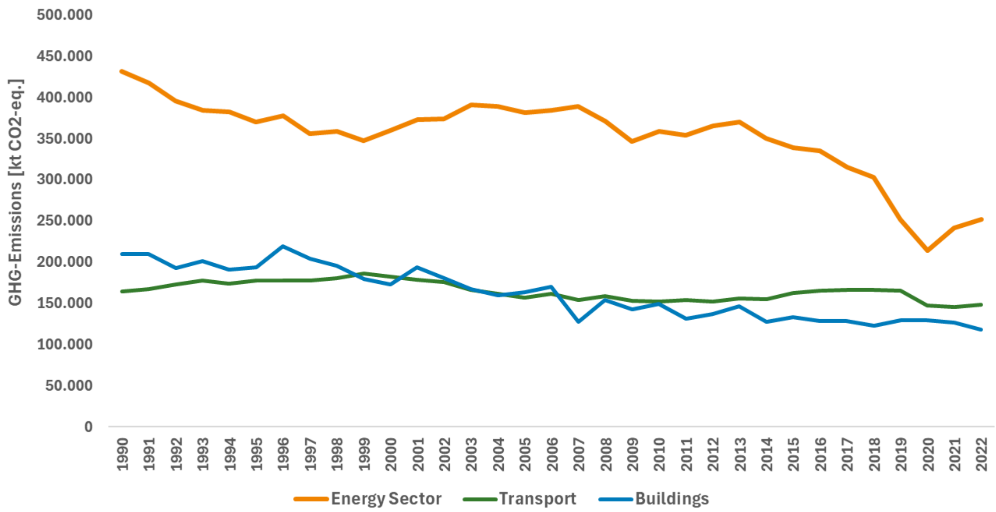
We begin by briefly outlining the current status of the transition and highlighting the main challenges that lie ahead. We then discuss the likely characteristics of the future electricity system and the current problems that the evolving market design will need to address. Based on this, we examine political-economic distortions and uncertainties that are contributing to today's investment reluctance. This overview of identified challenges sets the stage for the solution-oriented proposals that follow later in the study.

## 2.1 SYSTEM DEVELOPMENT TO DATE AND ITS OUTLOOK

When analysing system developments, it is important to differentiate between how the fundamental factors (e.g. power plants, generation mix, etc.) develop and what triggers these developments. This chapter focuses on the presentation of the developments of fundamental factors. Building on this, we will discuss how these developments can be incentivised in a sustainable manner later in the study.

The primary goal of the transformation is to decarbonise the energy supply. Figure 1 shows the $CO_2$-emissions from electricity supply, road transport and heat supply.

*Figure 1: Development of Energy-Related GHG Emissions in the Energy Sector, the Transport Sector and the Building Sector*




*Source: own illustration, data from UBA (2023).*

The figure clearly shows that considerable progress has already been made in reducing $CO_2$-emissions in the energy sector. However, further emission reductions will be more challenging than past successes.

In contrast, the road transport and residential sectors (particularly space and water heating) have so far only seen moderate reductions compared to the energy sector. Both sectors are expected to decarbonise primarily through increasing electrification – with heat pumps and electric vehicles playing a key role in this process.

TECHNOLOGICAL INNOVATION CONTINUOUSLY UNLOCKS NEW, ECONOMICALLY VIABLE POTENTIALS FOR DECARBONISATION AND FLEXIBILITY.

From an economic perspective, it makes sense to first exploit the most cost-efficient options for emission reductions. While electricity generation has benefited primarily from advances in wind and solar power technologies, the other two sectors are now seeing momentum from recent innovations in heat pumps and electric vehicles.

Yet technological development is far from complete. Large-scale heat pumps, for instance, are making noticeable progress. There are also signs that geothermal energy may benefit from innovative drilling technologies originally developed for fracking, which could unlock additional potential through deep geothermal applications. This opens up the possibility of decarbonising the heating sector more cost-efficiently than previously assumed.

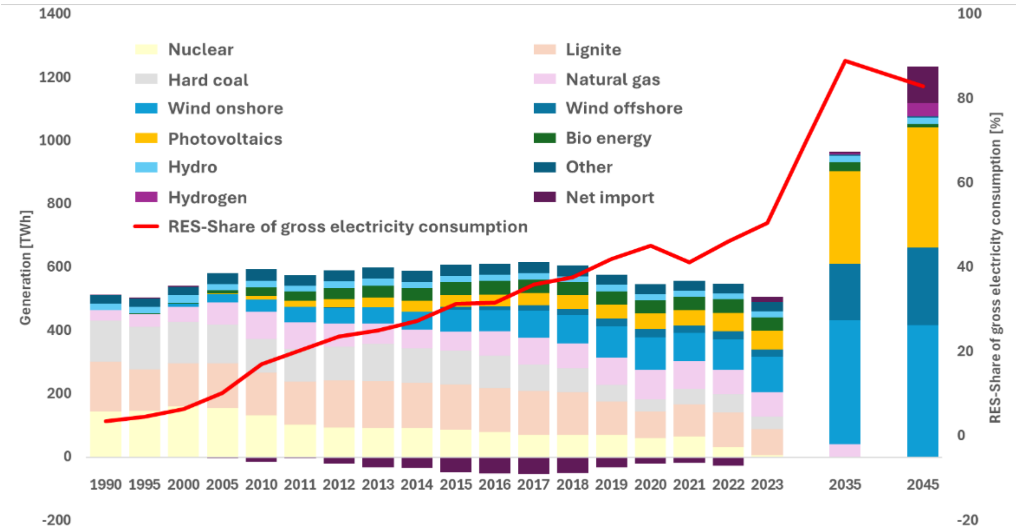
Of course, current efforts should not be slowed in anticipation of future innovations. Rather, this trend underlines the value of harnessing existing cost-efficient potentials as early and comprehensively as possible in order to achieve efficient decarbonisation. Should new technological options become available in the meantime, they can help reduce total system costs further.

### Renewable Energies Are at the Heart of the Decarbonisation

The electricity sector plays a central role in the decarbonisation of other sectors. To illustrate this, we take a closer look at past and potential future developments in electricity supply. It is important to emphasise that this does not represent a planned pathway for the power system over the next 20 years. Rather, it outlines one possible trajectory based on current knowledge, providing a rough sense of direction. The aim of this analysis is to derive key characteristics that the future electricity system will likely need to fulfil, based on plausible developments.

Figure 2 shows the evolution of the generation mix in recent years, as well as a possible future trajectory based on the T45-Strom scenario from the German Federal Ministry for Economic Affairs and Climate Action's long-term scenarios (BMWK 2024a). While the actual future may unfold differently, the figure illustrates the general direction of decarbonising the energy system.

*Figure 2: Development of the Generation Mix and the RE Share of Gross Electricity Consumption*



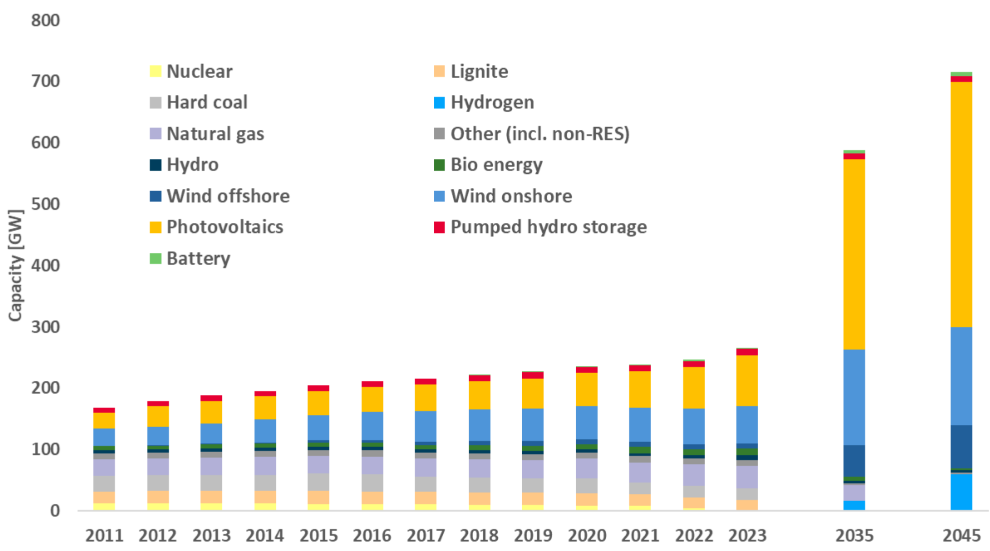

*Source: AGEB (2024) and BMWK (2024a).*

It is a remarkable achievement that in 2023, 51.8% of gross electricity consumption was covered by renewable energy sources. At the same time, the figure also illustrates that the challenges ahead should not be underestimated – particularly given that electricity consumption is expected to rise in the coming years.

### The Transformation Requires a New Understanding

We now turn to a discussion of how installed generation capacity may evolve. Figure 3 makes it clear that the transformation is not just about replacing fossil and nuclear generation capacity. Rather, the system transformation involves multiple dimensions. To implement the intended decarbonisation strategy, a fundamental shift in perspective is needed: towards an electricity system with a significantly larger number of generation and consumption units – and a much greater degree of flexibility.

*Figure 3: Development of Installed Capacity*



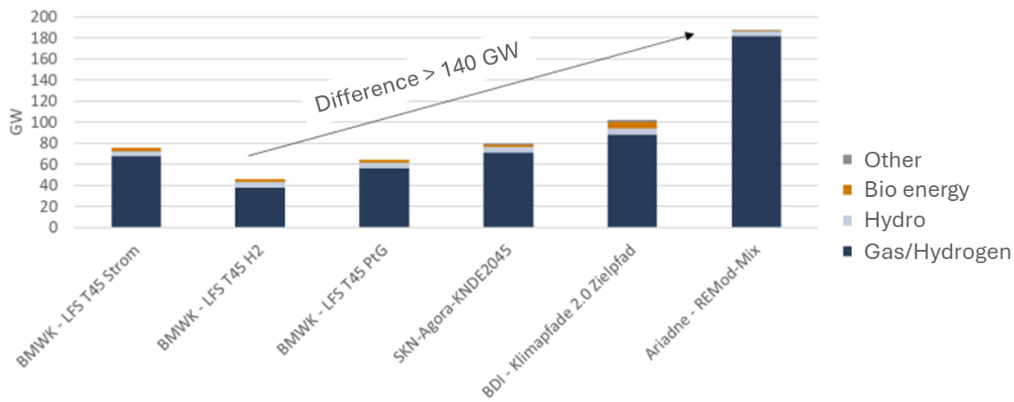

Source: Own illustration, data from BNetzA (2024a) and BMWK (2024a).

To decarbonise the mobility and heating sectors, a high level of renewable generation capacity is required. This means that the role of the future electricity system will differ significantly from that of the past. Due to the variability of primary energy sources such as sun and wind, a broad range of flexibility options will be needed to ensure security of supply across all sectors.

As shown in Figure 3, thermal generation capacity declines significantly over time in this scenario. While around 83 GW of fuel-based generation capacity was available in 2023, this figure falls to approximately 63 GW by 2045 in the long-term scenario developed by the Federal Ministry for Economic Affairs and Climate Action (BMWK). Of this, around 60 GW is expected to be hydrogen-based. This capacity is intended solely to meet residual demand – i.e. electricity demand that cannot be covered directly by renewable energy or indirectly via storage. In this way, the use of renewable energy is maximised, while the use of hydrogen – which is expected to be more expensive – is limited.

It is important to note that this scenario should not be interpreted as a forecast. Depending on the underlying assumptions and modelling approaches, the results of long-term scenario analyses can vary considerably. This uncertainty – especially with regard to future demand for controllable capacity, which depends on factors such as electricity demand, flexibility, and the expansion of PV and wind – has been illustrated by the Platform Climate-Neutral Power System (PKNS) of the BMWK in the following figure.

*Figure 4: Scenario Comparison for Controllable Power Plant Generation Capacity in 2045*



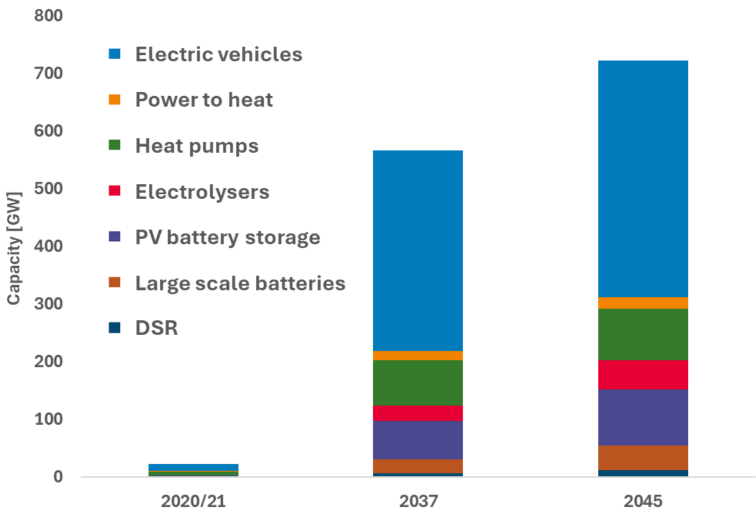

*Source: BMWK (2023a).*

The comparison of scenarios illustrates that estimates of the required controllable generation capacity can vary significantly. In Chapter 4, we take a closer look at the assumptions needed to model future developments.

## Increasing Decentralisation and Complexity

The development of installed capacity, as shown in Figure 3, indicates that the decentralisation of electricity generation will continue to increase. At the same time, the decarbonisation requirements in the heating and transport sectors make it clear that the aggregated price-sensitive demand from decentralised consumption technologies is also expected to rise significantly (see Figure 5).

*Figure 5: Development of Decentralised Flexibility Options*




*Source: BNetzA (2023a), own assumptions.*

Figure 5 shows that decentralisation and the number of different technologies with significant loads and capacity will increase significantly. This development also signals a marked rise in the complexity of the electricity system. The increasing complexity manifests across several dimensions:

- The cumulative load of decentralised technologies grows significantly.
- The number of consumption units requiring coordination rises considerably.
- The decentralisation of flexible demand increases.
- The price elasticity of electricity demand becomes more pronounced.
- More flexible capacity is connected at lower voltage levels.
- Sensory technology and data exchange expand.
- Substitutability of consumption, temporal shifting options, and storage capabilities increase.
- The cumulative capacity for feeding energy back into the electricity grid increases significantly.

This growing complexity raises coordination requirements between consumption units, storage options, the electricity grid, increasingly decentralised generation technologies, and electricity markets.

## INFOBOX: PROPERTIES OF COMPLEXITY

Complexity is a property of systems that consist of multiple interdependent elements, often leading to partially unpredictable and nonlinear outcomes. The distinction becomes particularly clear when comparing complex systems to merely complicated ones:

- Complicated systems: The elements of complicated systems interact in a linear and predictable way. A clockwork mechanism, for example, is complicated – because the interactions of its components can be precisely calculated and produce predictable results.
- Complex systems: The interactions within complex systems are dynamic and often characterised by nonlinear, amplifying or dampening feedback loops. Ecosystems, for instance, are typical examples of complex systems.

The increasing number of decentralised technologies adds to the system's complexity – not least because their market behaviour depends on human preferences and their response to incentives. These factors are not fully predictable and may reinforce or offset one another over time.

Complex systems are typically also characterised by emergence and self-organisation. They adapt to both internal and external factors through decentralised, self-organising processes. Complexity also entails a form of ambiguity, as the specific outcomes of complex constellations are, by definition, not calculable.

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The increasing complexity brought about by the growing number of decentralised generation units and price-elastic consumption technologies gives rise to new requirements for how the electricity system is organised.

## 2.2 PROBLEM DESCRIPTION

Having discussed the foreseeable framework conditions in the previous chapter, we now turn to several challenges that are emerging both now and in the future. The challenges facing the power system are often reduced to what is known as the Dunkelflaute – periods of low solar and wind generation. While this is certainly a relevant aspect of security of supply, a sustainable solution requires a broader understanding of the problem. In our view, the challenges are far more multifaceted. If we focus only on one isolated issue, the resulting responses will inevitably fall short of addressing the full complexity – and this, in turn, will likely necessitate the next policy intervention in short order.

For example, the Platform Climate-Neutral Power System (PKNS) identified the Dunkelflaute as the central challenge. The corresponding technological response assumed that – in addition to imports from the internal electricity market and a limited contribution from biomass – only (hydrogen-based) gas-fired power plants would be able to address the issue (BMWK, 2023a).

This narrowing of the solution space can create the impression that no allocation task remains. After all, if the solution has already been identified – namely (hydrogen-ready) gas power plants – one might conclude that there is no further need for allocation through market mechanisms.

We do not share this diagnosis of the problem, nor do we agree with the simplified anticipation of a single technological solution. As a consequence, we also reject the notion that market-based processes have no role to play in solving the organisational challenge. Over the course of this study, we will gradually develop an approach to addressing this coordination problem more comprehensively.

Before exploring potential solutions, we first provide an overview of the current challenges in order to establish a sustainable basis for problem-solving.

- SECURITY OF SUPPLY: This is arguably the most frequently cited and politically debated topic. At its core, it concerns the ability to avoid involuntary power cuts for consumers – as would be the case in a brownout, in which certain consumers or distribution networks are temporarily disconnected. Security of supply generally refers to the ability to maintain reliable electricity supply at the bidding zone level.
- SYSTEM SECURITY: When asked about security of supply, many stakeholders are in fact referring to system security. This involves the ability of grid operators to operate the electricity system securely and to transport power to consumers. The challenge lies in physically implementing the outcome of the electricity market while accounting for limited transmission capacity.[1] The resulting need for redispatch requires dispatchable generation (or curtailment of load) within the congested regions.
  This issue is particularly urgent from a climate policy perspective. Currently, the grid reserve is used to keep power plants operational that have already been earmarked for decommissioning, so they can be deployed for redispatch if needed. As coal is phased out, additional

[1] To maintain compliance with the n-1 criterion, a range of additional system services must also be provided (e.g. black start capability and reactive power provision). However, given the focus of this study, we concentrate on the management of network congestion. A large share of the challenges can be addressed through local measures which, while interacting with broader market design aspects, go beyond the scope of this study. As part of the PKNS process (Meyer-Braune and Lopion, 2023), the TSOs have presented various proposals for regional measures.

dispatchable capacity will be required. Otherwise, the coal phase-out may be delayed for system security reasons, contrary to political goals.

- DECARBONISATION OF ELECTRICITY GENERATION: Despite the notable progress illustrated in Figure 1, the need to continue decarbonising the power sector remains urgent. In 2020, the German government negotiated a coal phase-out by 2038. The current coalition agreement expresses the ambition to ideally bring this forward to 2030. This would result in a significant amount of generating capacity in southern Germany being shut down – capacity that is currently essential to maintain system security.
- DECARBONISATION OF THE HEATING AND TRANSPORT SECTORS: Given past trends in emissions, it is crucial to significantly accelerate the decarbonisation of heat supply and road transport. Based on current technologies, this is expected to be most cost-efficient through widespread electrification of both sectors. This, in turn, places new demands on the electricity system, especially regarding the integration of a wide range of new consumption units with considerable aggregated load. In addition to technical requirements, public protests in 2023 highlighted the importance of societal acceptance. These two sectors are more closely tied to people's everyday lives than electricity generation itself – which increases expectations regarding the design of the transformation process.
- INTEGRATION OF RENEWABLE ENERGY SOURCES: As shown in Figure 3 renewable generation capacity is expected to increase significantly. The integration of this energy requires a new scale of flexibility across various system components. In addition, the fundamental characteristics of renewables – such as variability, limited predictability, and steep ramping – require adjustments to several market and regulatory processes. These include the support scheme for renewables, regulatory frameworks for grid expansion and digitalisation at both transmission and distribution levels, and the operational organisation of grid operation, particularly redispatch.
- $H_2$-MARKET RAMP-UP: There is broad consensus that hydrogen will play a key role in decarbonising the energy system and industrial processes – a position supported by numerous studies. However, the precise nature of hydrogen's role is subject to considerable ambiguity, as its techno-economic characteristics differ substantially from those of natural gas. It remains unclear how much hydrogen will be domestically produced and how much will be imported – and by when. One driver behind the transformation of the energy system has been the experience of disrupted natural gas deliveries from Russia following the invasion of Ukraine. This brings new requirements for hydrogen-exporting countries.

The ambiguity around future hydrogen availability is partly due to uncertainty about its price. Various studies estimate a wide range of production costs for green and blue hydrogen. However, in a market setting, production costs are merely a rough indicator of market prices. Prices are determined by supply and demand and typically reflect the marginal supplier. Many oil-producing countries, for instance, have production costs well below global market prices.
Hydrogen also has a higher volume per energy unit compared to natural gas. As a result, hydrogen storage becomes important for achieving a comparable level of short-term supply security.
There is also disagreement about how hydrogen will be used in the future. While a broad majority of academic studies suggest that hydrogen will play only a limited role in heating, others assume it could partly replace natural gas. From an economic perspective, the extent of hydrogen use will depend on infrastructure availability and the relative price of hydrogen compared to its substitutes. At present, we are seeing a number of innovations across the electricity, transport, and heating sectors that could become relevant for the allocation of hydrogen.

- $H_2$- TECHNOLOGY AVAILABILITY AND SECURITY: The new role of hydrogen in electricity supply could bring various systemic risks. Security of hydrogen supply and storage was already discussed in the previous section. In addition, there are technology-specific risks associated with the first generation of hydrogen turbines. Hydrogen is particularly reactive and has a high flame temperature. Moreover, there is still limited operational experience with hydrogen-fired power plants at relevant scale. We do not yet know how the materials used in these plants will behave after several years of use. If the future electricity system relies heavily on the availability of hydrogen and the reliability of related technologies, it must be ensured that the associated risks are manageable.

These issues are strongly interdependent. Ideally, they should be addressed in an integrated way through a well-designed market framework. However, current regulatory conditions stand in the way of such solutions due to a range of frictions as well as misaligned and distorted incentives.

## 2.3 THE EFFECTS OF CURRENT FRAMEWORK CONDITIONS

The regulatory and political environment shapes the behaviour of market participants. Incentives for economic action are driven both by market signals –

in the form of prices – and by regulatory provisions. These provisions can either support or hinder desirable developments.

A key economic concept used throughout this chapter and the broader study is the notion of opportunity costs, which provides an analytical lens for evaluating the effectiveness of current framework conditions.

### INFOBOX: OPPORTUNITY COSTS

Opportunity costs play a crucial role in decision-making – both in business and in policymaking. In essence, opportunity costs represent the value of the best alternative forgone when a decision is made. For example, if public funds are used to support a new technology, that money is no longer available for other policy measures.

When designing regulatory frameworks – and when acting within them – it is important to take opportunity costs into account. The concept of the "value of the alternative" is broad. It also includes path dependencies created by political decisions, whose long-term consequences are often difficult to foresee at the time the decision is made. Still, opportunity costs should be considered as comprehensively as possible before decisions are finalised.

Opportunity costs are relevant in all economic transactions, as they influence price formation. For example, if a market participant can sell a fuel and a $CO_2$ certificate on the market at a given price, they will only use these inputs for electricity generation if the resulting revenue from selling the electricity is at least comparable.

Likewise, a consumer will only purchase a product if the perceived benefit exceeds that of an alternative product they would otherwise consume. For a transaction to occur at a given price, it is necessary that the parties involved attribute different levels of value to the good in question.

This seemingly simple logic forms the foundation of all value-creating market processes. Markets coordinate transactions involving different goods, across various markets and points in time. These interdependencies are organised in a utility-maximising way through the decentralised coordination mechanism of price signals – the so-called invisible hand of the market.

In this chapter, we discuss the effects of three current framework conditions on the ability of market participants to manage the transformation phase constructively:

- Misaligned and distorted political-economic incentives
- Ambiguity regarding future developments
- Dealing with increasing complexity

To understand the impact of these conditions, we first examine the underlying concepts in greater detail across the following three subsections.

### 2.3.1 Background of Misaligned and Distorted Political-Economic Incentives

Incentives play a central role in economic activity – both in coordinating market participants and in achieving policy objectives. The decision-making of market actors involves many factors, but for the sake of simplicity, we can assume that it largely follows a form of cost–benefit analysis, in which economic aspects tend to carry the greatest weight. Business decisions are typically guided by financial performance indicators.

Very simply put, incentives can be either rewarding or punitive. High prices signal that it is worthwhile to expand supply. Taxes and levies on certain products reduce profitability and signal that such activities are less attractive and should be curtailed.

Misaligned and distorted incentives lead to undesirable outcomes. For example, they may result in decisions that are beneficial to individual companies, but harmful to the broader economy or society as a whole.

Well-designed, goal-aligned incentives have a positive effect both at the microeconomic level and from a societal perspective. They align private interests with overall welfare. For instance, when prices rise, profit-oriented companies are incentivised to increase production, which in turn counters the price increase – to the benefit of consumers. This creates a new market equilibrium from which both producers and consumers stand to gain.

Regulatory or political incentives are usually introduced with good intentions. However, this does not mean that the actual incentive effects match the original intentions. It is a fallacy to evaluate policy measures based on their stated goals alone – they must be judged by their outcomes.

Incentives are multifaceted and often complex in their implementation. Even individual political statements can create incentive effects, sometimes without policymakers being fully aware of the consequences. These are referred to as unintended consequences.

One field of economics that explores the implications of incentive structures is game theory. When one actor's decisions depend on the actions of others, game-theoretic reasoning can offer valuable insights. Strategic considerations are part of how rational market participants make decisions. The most well-known example is the prisoner's dilemma, which illustrates how interdependent decisions can lead to suboptimal outcomes – and why understanding incentive effects is critical for designing effective policy frameworks.

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### INFOBOX: THE PRISONER'S DILEMMA

The prisoner's dilemma is a thought experiment used to explore the effects of incentives and to support rational decision-making under uncertainty.

Two criminals are held in separate cells by the police to prevent them from communicating. Each is presented with the same choice:

- If both remain silent (i.e. cooperate), the police only have enough evidence to sentence each of them to one year in prison.
- If both confess (i.e. do not cooperate), they will each receive a three-year sentence.
- If one confesses and the other remains silent, the confessor is released immediately, while the silent accomplice receives ten years in prison.

This decision can be analysed using a decision matrix, which illustrates whether cooperation or defection is the rational choice.

| | | Prisoner A | |
|---|---|---|---|
| | | **cooperation** | **Non-cooperation** |
| **Prisoner B** | **coop.** | 1<br>1 | 0<br>10 |
| | **Non-coop.** | 10<br>0 | 3<br>3 |

Two scenarios can be considered from the perspective of one of the criminals (say, Prisoner B):

- SCENARIO 1 - PRISONER A REMAINS SILENT: If Prisoner B also remains silent, he receives one year in prison. If he confesses while A stays silent, he is released. From this perspective, it is rational for B to defect and confess.
- SCENARIO 2 - PRISONER A CONFESSES: If B remains silent, he receives ten years. If B also confesses, he receives only three years. Again, it is rational for B to confess to avoid the maximum sentence.

Game theory shows that defecting is the rational choice in both scenarios – it is the dominant strategy. Yet this leads to a paradox: mutual cooperation would yield a better outcome overall (only one year each), minimising total prison time. This reveals the tension between individual rationality and collective welfare.

The outcome in which both prisoners confess is called a Nash equilibrium – a situation in which no actor can improve their position by unilaterally changing their strategy.

A special form of the prisoner's dilemma is the free-rider problem. This occurs when actors benefit from a resource without contributing to its funding. Because fewer actors are willing to pay, price signals are distorted, and the resource is provided at a level below the social optimum. Even benevolent actors have rational reasons not to cooperate in such situations. The result is again a Nash equilibrium – but one that leads to socially suboptimal welfare outcomes.

This illustrates that well-functioning incentives depend on the design of the regulatory framework. One cannot rely on the goodwill of actors alone – incentive structures must be aligned accordingly.

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In the prisoner's dilemma, the police officer creates an incentive structure in which it is rational for the criminals to act uncooperatively. Good market design, by contrast, aims for the exact opposite. Even actors who are not motivated by societal considerations should, under a well-designed market framework, be incentivised to act in a way that aligns with public goals – out of self-interest.

The art of market design lies in creating conditions that incentivise actors to behave cooperatively, in a manner that promotes societal welfare and prevents free riding. This can be achieved, for instance, when markets are characterised by a high degree of competition.[2]

A GOAL-ALIGNED MARKET DESIGN INCENTIVISES ACTORS TO ENGAGE IN WELFARE-ENHANCING BEHAVIOUR.

[2] By contrast, if market power is concentrated in the hands of a few actors, they may be able to influence market outcomes in a way that benefits them at the expense of society.

By contrast, when frameworks are designed in a way that makes uncooperative behaviour rational, we speak of misaligned incentives. In such cases, economic actors benefit by acting in a way that is detrimental to society – they increase their profit at the expense of the common good. It is important to note that this does not reflect malicious intent. Rather, it is rational behaviour resulting from the structure of incentives.

To a limited extent, the suboptimal outcomes generated by misaligned incentives can be tolerated. However, in most cases, adjustments to the framework conditions become necessary in order to contain the welfare losses.

### Example of Suboptimal Framework Conditions: Undersubscribed Renewable Energy Auctions

For many years, auctions for onshore wind expansion have regularly been undersubscribed. In other words, there is insufficient competition for the available support. Participating actors behave rationally and seek to maximise profits. As a result, bids are not primarily based on the actual levelised cost of electricity (LCOE), but rather on the administratively defined price cap. The price cap thus becomes necessary to limit the bids submitted by market participants.

The downside of this regulatory intervention is a reduction in market agility in response to changing conditions. As recent years have shown, inflation, the stability of global supply chains, and the level of capital costs (driven by interest rate changes) can shift rapidly.

Fixed bid caps do not reflect these dynamics. Consequently, frequent adjustments are needed to keep the framework aligned with current conditions. However, such administrative adjustments are always subject to delays and incomplete information on the side of the regulator. In addition, each regulatory change introduces a new layer of ambiguity for affected market participants.

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#### INFOBOX: INFORMATION ASYMMETRIES

Access to information differs significantly between market participants and policymakers. Detailed information often only becomes available in the specific context of contract negotiations. Typically, contract terms evolve throughout the negotiation process. Competition is key to revealing the true costs and conditions. An initial request for information, by contrast, is unlikely to uncover actual cost structures – it merely reflects what actors are willing to disclose.

Moreover, market participants have no incentive to share full and accurate information with political decision-makers. Competition and cost pressure may be uncomfortable, but they are necessary to drive cost efficiency and innovation. When interacting with policymakers, however, companies tend to communicate information that supports favourable regulatory treatment. This is not necessarily done with ill intent, but rather reflects a desire for comfortable operating conditions. Without competitive pressure, the true conditions cannot, by definition, be revealed.

Regulatory frameworks developed under incomplete information can therefore never be economically or socially optimal – even when all actors, whether political or commercial, act in good faith and with the best of intentions.

Due to information asymmetries, it is inherently impossible to determine the ideal bid cap in renewable energy auctions. At best, a cap can be defined that is "good enough." The consequences are clear: if the cap is set too low, auctions may remain undersubscribed; if it is set too high, market participants enjoy excessive margins – at the expense of society.[3]

In other words, administrative decisions always involve trade-offs – they are not optimisations. Political influence can further increase the degree of suboptimality in these decisions.

If there were sufficient competition, market participants would factor in the prevailing conditions – such as supply chain constraints or changes in interest rates – into their bids. Competition would ensure that the support levels rise only to the extent that is strictly necessary.

Insufficient competitive intensity is thus a clear example of suboptimal framework conditions, which can create misaligned incentives. The regulatory interventions required to address such shortcomings are themselves trade-offs, and they often necessitate additional interventions, which by their nature move even further away from ideal market outcomes.

### The Political Communication of the Coal Phase-Out

In the 2021 coalition agreement (Bundesregierung, 2021), the government announced the goal of ideally bringing forward the coal phase-out to 2030.[4] The

[3] In the case of RES auctions, a variety of framework conditions naturally influence the level of competition – such as permitting procedures, for example.

[4] At the time of the study, the coal phase-out scheduled for 2038, as negotiated by the previous government, remains anchored in legislation.

term "ideally" implies a certain degree of ambiguity, likely linked to the impact on security of supply and system security. In the same document, under the section on 'market design', the coalition also stated its intention to examine the introduction of technology-neutral capacity mechanisms.

For potential investors in dispatchable capacity, the question arises: should investment decisions be made now, in anticipation of the earlier phase-out date? The effect of ambiguity on investment decisions will be discussed in the next section. Here, we focus primarily on the incentive effects of the political announcement itself.

The challenge lies in the timing mismatch: investment decisions must be made well in advance – considering long lead times for planning, permitting, and construction – while the final decision to bring forward the coal exit has not yet been made. This creates a situation in which investment and phase-out decisions influence one another, but are temporally decoupled.

This raises the question: how are such political announcements interpreted by companies from a game-theoretic perspective? After all, from a policy perspective, it would be desirable for companies to behave cooperatively and adapt their investment strategies in line with the announced earlier phase-out. That, at least, seems to be the political expectation.

However, from the perspective of companies – taking into account strategic and game-theoretic considerations – different conclusions may be drawn. At first glance, the situation can be reduced to two basic dimensions: cooperation vs. non-cooperation, and early phase-out vs. maintaining the original timeline.

Yet the situation is more complex than a classic prisoner's dilemma. In this case, a temporal dimension adds pressure, especially on political decision-makers. At the same time, companies can send signals – either by investing or by holding back investment – which in turn can create pressure on policymakers. When taking these additional dynamics into account, companies' strategic considerations might (in simplified terms) look as follows:

- SCENARIO 1 - EARLY COAL PHASE-OUT:
  - Cooperate: New investments could, in the best case, become viable despite the accelerated expansion of renewables.
  - Not cooperate: By withholding investment, the market becomes tighter, and remaining plants earn higher margins.
  - In this comparison, withholding investment carries less risk and potentially yields higher returns.

- SCENARIO 2 - ORIGINAL COAL PHASE-OUT TIMELINE:
  - Cooperate: New investments would not be profitable due to overcapacity.
  - Not cooperate: Withholding investment simply continues the existing strategy.
  - In this case as well, investment restraint is the rational choice, as it minimises the risk of sunk costs.

Investment restraint, or non-cooperative behaviour, is therefore the dominant strategy under current framework conditions. This does not mean that companies are unwilling to invest. Rather, the existing conditions make it more rational not to invest – and to signal this non-investment to policymakers.

As a result of politically induced incentives, a Nash equilibrium emerges (see Infobox on the Prisoner's Dilemma), in which companies hold back investments (strategic wait-and-see) and the coal phase-out proceeds on the originally planned timeline.

There is, however, a further incentive that reinforces this pattern: the signal effect of investment restraint, combined with political time pressure, increases the likelihood that policymakers will respond by offering financial support to incentivise investment. This willingness has already been hinted at in the coalition agreement, which includes an announcement to examine capacity mechanisms.

In light of these political signals – the ambition to bring forward the coal phase-out, and the willingness to consider capacity payments – the game-theoretic interpretation of the government's position is straightforward: "If you don't invest, we'll pay you to do it."

THE COMMUNICATION AND MANAGEMENT OF THE COAL PHASE-OUT CREATE DISTORTED INCENTIVES THAT UNDERMINE BOTH INVESTMENT READINESS AND THE PHASE-OUT ITSELF.

From a strategic perspective, this sends a clear incentive to companies: "Whatever you do – don't invest now, or you might miss out on subsidies." This type of political communication, in combination with fixed target dates, reduces the likelihood of achieving the coal phase-out in a smooth and efficient manner.

Investment restraint by companies is, therefore, a rational and predictable outcome of the current policy framework. In Section 6.1.1, we discuss an alternative approach to decarbonisation. First, however, we turn to the issue of ambiguity, which also plays a central role in shaping investment decisions.

## 2.3.2 The Impact of Existing Ambiguity

In this section, we examine the degree of ambiguity currently faced by potential investors as a result of prevailing policy and regulatory conditions. We highlight the extent to which this ambiguity contributes to the current reluctance to invest.

On the one hand, political decisions and regulatory interventions can increase ambiguity. On the other hand, inaction – the absence of political decisions – can also maintain or exacerbate ambiguity, thereby complicating investment planning.

When designing economic framework conditions, the objective should be to create predictable environments that can be navigated and acted upon by market participants. However, when allocation decisions are shifted from the market to the political decision-making process, ambiguity increases. This is because politically determined frameworks are inherently subject to revision and renegotiation. In such cases, the likelihood of further unforeseeable interventions typically increases as well.

We begin by conceptually distinguishing ambiguity from other forms of uncertainty. We then go on to discuss specific instances of ambiguity currently affecting the investment climate.

### The Logic of Uncertainty

All decisions are made under conditions of uncertainty, as the future is inherently unpredictable. This applies especially to energy sector investment decisions, given their high capital intensity and long amortisation periods. In the previous section, we discussed how current policy and regulatory conditions may act as distorted incentives, leading to investment restraint. The current level of ambiguity may offer an additional explanation – one that is conceptually distinct from incentive-related effects.

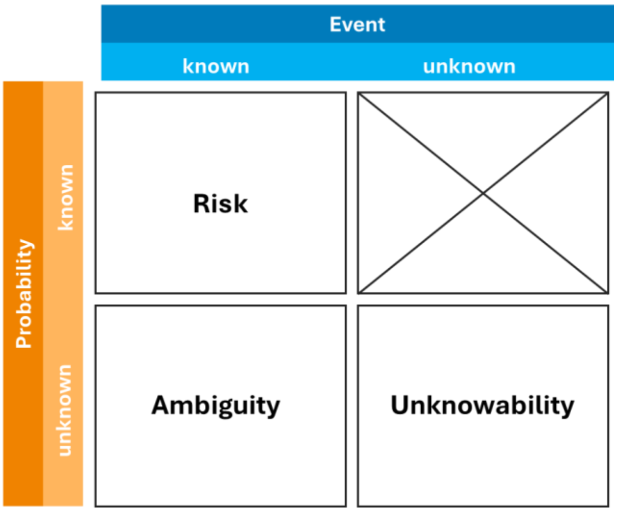
A natural human response to uncertainty is the desire for greater control, in order to increase the perceived level of security. In energy policy, this often translates into more political intervention in market processes. The relevant question, however, is whether such interventions are actually well-suited to addressing the underlying source of ambiguity, or whether there are more effective approaches for managing specific aspects of uncertainty.

To explore this question, we begin by examining different conceptual categories of uncertainty. We then analyse how selected types of energy-sector ambiguity affect investment and market behaviour.

## INFOBOX: CATEGORIES OF UNCERTAINTY

The classification and handling of uncertainty can be traced back to Frank H. Knight (1921) and depends on the type and extent of information available at the time a decision is made. Two informational dimensions are particularly relevant:

1. Whether the possible outcomes are known, and
2. Whether their probabilities can be reasonably estimated.




For logical reasons, we can exclude the case in which outcomes are unknown, but their probabilities are known. Based on this framework, the overarching concept of uncertainty can be divided into three categories: risk, ambiguity, and unknowability.

- RISK: When the possible outcomes are well-defined and their probabilities can be reasonably estimated – for example, based on empirical data – the decision is considered to involve risk. Most short- to medium-term economic decisions fall into this category. Risks are calculable, but there are no guarantees of a positive outcome. Generally, the potential for profit increases with the level of risk taken, as some actors are unwilling to bear higher risk – reducing competition and increasing potential margins for risk-tolerant participants.
- AMBIGUITY: When the possible outcomes are known, but their probabilities cannot be reliably estimated using available data or methods, the decision involves ambiguity. Political decisions typically fall into this category – especially over longer time horizons. This is why stable policy frameworks are

so important for investment climates. A classic negative example is retroactive policy changes, which are a particularly damaging form of political ambiguity.

- UNKNOWABILITY: When neither the possible outcomes nor their probabilities can be assessed, the situation is one of unknowability – also known as "unknown unknowns." When the consequences are significant for an entire industry or sector, such events are sometimes referred to as black swans. Examples include technological disruptions that fundamentally change market structures.

By categorising decision situations in this way, more targeted and appropriate decisions can be made. This classification thus forms a foundational tool for decision-making under uncertainty. The more information is available – and the more that information affects outcomes – the better the uncertainty can be managed through market mechanisms.

In this section, we focus specifically on ambiguity, as dealing with risk is a normal part of economic activity.

Political decisions play a major role in shaping the level of ambiguity faced by investors. A lack of decisions to establish long-term stable frameworks can increase ambiguity. Conversely, short-term interventions can also heighten ambiguity, as they affect both the short- and long-term ability of investors to form expectations. Without the ability to form reliable expectations, it is not possible to make rational investment decisions.

In the case of listed companies, for example, it is the responsibility of the supervisory board to assess the rationale behind major investment decisions. This becomes difficult in the absence of stable assumptions.

In the following, we discuss several selected examples of ambiguity that may currently be discouraging investment. Section 6.1 explores possible solutions to address these challenges.

### Announcement of the (Accelerated) Coal Phase-Out

We have already discussed the announcement of the proposed earlier coal phase-out in the previous section in terms of its incentive effects. Another important aspect is the creation of ambiguity through the announcement of a fixed phase-out date – even though, at first glance, such a date may appear to reduce uncertainty.

This issue extends beyond the question of whether the coal phase-out is accelerated or not. To meet climate targets, coal-fired power generation must be phased out – unless carbon capture and storage (CCS) is politically accepted. The real question is how this transition can be organised in a way that does not unduly compromise security of supply or economic welfare.

A politically fixed exit date is, by its very nature, ambiguous. A future government may revise a previously agreed timeline. In Germany, we saw this in 2010 when the phase-out of nuclear energy was postponed. More recently, Belgium extended the operating lives of its nuclear power plants by another ten years.

Fixed exit dates create planning ambiguity for other investors. A new power plant that is economically viable under the current timeline may become unprofitable if the exit date is postponed. In this way, ambiguity acts like a distorted incentive: it increases the perceived risk of investing in new (lower-emission) technologies.

A particularly illustrative example of how politically fixed dates can increase ambiguity is the Emission Performance Standard (EPS) in capacity mechanisms.

### INFOBOX: EMISSION PERFORMANCE STANDARD IN CAPACITY MARKETS

The European Electricity Market Directive (2019) introduced an Emission Performance Standard (EPS) that prohibits power plants emitting more than 550 g $CO_2$/kWh (or 350 kg $CO_2$/kW/year) from participating in capacity mechanisms after mid-2025. The rationale behind this measure was to avoid a fossil lock-in, whereby high-emission plants could offset rising carbon costs under the EU Emissions Trading System (EU ETS) through increased capacity payments.

However, the recent reform of EU Electricity Market Regulation (2024) introduced a derogation clause, allowing Member States to postpone the application of the EPS until the end of 2028, subject to formal approval.

The EPS is another example of how setting a fixed date can create ambiguity. This ambiguity complicates investment decisions in low-emission technologies. Poland, for instance, is likely to make use of the derogation and postpone the application of the EPS in its capacity market. As a result, the business case for cleaner technologies – which had been made under the assumption that the original EPS deadline would apply – has weakened.

In contrast, companies that own coal-fired power plants and deliberately withheld investment are now rewarded by the delayed introduction of the EPS. This aligns with the previously discussed definition of a distorted incentive. Furthermore, by signalling investment restraint, companies may increase the likelihood that policymakers will postpone phase-out decisions, reinforcing the incentive to delay.

If, on the other hand, decommissioning decisions are based on internal economic profitability assessments, this leads to predictable framework conditions and reduces ambiguity for investors. We explore alternative approaches to organising the coal phase-out in Section 6.1.1.

### Interventions in Price Formation

Perhaps the greatest source of ambiguity for power plant investments stems from interventions in price formation, especially when fundamental market scarcities become visible. For this reason, sceptics of market-based incentives felt vindicated by the revenue clawbacks introduced during the energy crisis.

The uncertainty caused by the revenue cap mechanism is understandable from a business perspective. Moreover, the EU-level debate on potentially replacing the merit-order system with a split electricity market has further amplified this uncertainty.

At the same time, it is equally understandable that political actors felt compelled to protect households and businesses during a war-induced supply crisis. From an economic perspective, market interventions may be justified if there are significant market imperfections that result in consumers being excessively burdened – for instance, in cases of market power abuse.

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INFOBOX: UNINTENDED CONSEQUENCES

From the perspective of political decision-makers, it is understandable that they seek to address perceived problems. However, interventions in economic systems typically come with unintended consequences. In other words, interventions have a cost – one that is often not fully visible at the time the decision is made. In this sense, unintended consequences can be viewed as a form of opportunity cost.

One example of such a cost is the creation of path dependencies: a stakeholder group that receives public support once may be unwilling to invest without continued support in the future. Another example is a loss of trust in market processes, which can lead to a situation where additional interventions become necessary. This dynamic is also referred to as the "oil stain effect" (Ölflecktheorem), where one intervention spills over into others.

This is why economic theory advises that market interventions should only occur in the presence of clearly demonstrated market imperfections. Otherwise, the cost of subsequent corrective interventions often exceeds the benefits intended by the original policy measure.

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During the energy crisis, prices rose sharply due to a shortage of natural gas. The high market price reflected the (expected) scarcity of the primary energy source, gas. In doing so, it sent a scarcity signal that incentivised more efficient and conservative use of the fuel. The market-based allocation function worked as intended: consumers responded by reducing gas and electricity consumption and by investing in alternatives.

For example, demand for Power Purchase Agreements (PPAs) increased, and households and businesses invested in rooftop PV systems and electricity storage. In other words, markets reacted as they should in theory, with price signals triggering a range of decentralised solutions.

DURING THE ENERGY CRISIS, MARKETS RESPONED AS THEY SHOULD: PRICE SIGNALS TRIGGERED ADJUSTMENTS IN CONSUMPTION AND INVESTMENT, ALLOWING SCARCITY TO BE ADDRESSES EFFECTIVELY.

Intervening in the market – or specifically in price formation – does not eliminate the underlying scarcity of fuel or the need to use it efficiently. However, artificially dampening the price signal reduces the incentives for finding solutions. That said, it is undoubtedly important to protect vulnerable consumers during such phases. This, however, is far more effectively achieved by maintaining the price signal and targeting support at those who are unable to adapt and face real hardship.

In the political debate about future market design, the scarcity of primary energy carriers has played a surprisingly minor role. As a result, policymakers were not well prepared to protect society and the economy using appropriate instruments. Experience from the German and European discussions has shown that reactionary policy responses are rarely effective – and do not yield sustainable outcomes.

The revised Electricity Market Directive and Regulation (2024) ultimately do not include any of the more extreme market intervention proposals that were discussed at the height of the crisis. Instead, they provide frameworks for tools such as hedging obligations, designed to protect consumers from risky procurement strategies and free-riding. During the energy crisis, many suppliers that had relied on short-term procurement without hedging their delivery commitments were forced to declare insolvency. Looking ahead, companies will be expected to secure their supply obligations through longer-term contracts and hedging strategies.

What have we learned from this experience?

- Political decision-makers naturally seek to take action when it comes to protecting society and the economy.
- The scientific community should develop solution-oriented proposals for uncertain scenarios in advance – in order to inform and support policymakers in their decision-making.
- Markets responded exemplarily to the scarcity, triggering effective adjustments and decentralised solutions.
- Having more gas-fired power plants would not have made electricity supply more secure during a gas shortage.
- And most importantly: we need an agile approach to deal with new situations constructively and to learn from them – without resorting to overreactions or market interventions that might undermine trust in the welfare-enhancing function of markets.

In Chapter 6, we present proposals for how markets can be appropriately developed further – including ways to reduce ambiguity and improve investment conditions.

### The Reliability of Emissions Trading System

A particular form of ambiguity regarding future price interventions stems from questions about the political commitment to the EU Emissions Trading System (EU ETS). The number of available emission allowances declines each year, and the ETS plays a crucial role in incentivising investments in low-emission technologies. During the low-price phase of the 2010s, the Market Stability Reserve (MSR) was introduced to support the carbon price.

A steadily shrinking allowance cap is expected to lead to rising prices. However, this price increase is not necessarily continuous and may be accompanied by high volatility, depending on market expectations. In the past, periods of high allowance prices have triggered calls for intervention from various stakeholders. These interventions – and ongoing debates about further political interference – contribute to ambiguity regarding the credibility and durability of the ETS framework.

As the tightening of the cap accelerates in the coming years, discussions about further interventions are also likely to intensify. For the ETS to remain effective as an investment signal, it is crucial that the emissions reduction trajectory is maintained, and that interventions beyond the MSR are avoided.

### The Ramp-Up of the Hydrogen Market

One way to support decarbonisation is by temporarily storing renewable electricity in the form of hydrogen. The ramp-up of a new market is, by nature, accompanied by a high degree of fundamental ambiguity. Key questions include:

- What will hydrogen be used for?
- How much hydrogen will be needed?
- What prices can be expected?
- Where will the hydrogen come from?
- When will hydrogen be available, and in what quantities?
- How, in what form, and to which locations will it be transported?

These and other questions are closely interlinked and mutually dependent. For instance, the volume of hydrogen used in the economy typically depends on its price. Yet this already illustrates a core ambiguity. If policymakers wish to keep energy-intensive industries in Germany rather than see them relocate to regions with lower electricity and hydrogen prices, this likely implies a need for ongoing operational subsidies.

But how reliable is the political commitment to permanent industrial subsidies? The recent debate over the Climate and Transformation Fund (KTF) has shown that even strong political intentions do not necessarily translate into long-term certainty. Consequently, this ambiguity also makes it necessary to at least partially finance conversion costs. As previously noted: one intervention tends to lead to the next.

The financial backing of the hydrogen core network by the KfW (Germany's development bank) is intended to facilitate private investment through a repayment account mechanism. On the supply side, import routes are being explored, and the H2Global scheme is designed to bridge the gap between long-term supply contracts and the more short-term needs of hydrogen consumers.

However, neither supply-side nor infrastructure investments can proceed optimistically without a predictable outlook for future demand. One of the motivations behind the Power Plant Strategy (KWS) is to act as a reliable offtaker and help stimulate initial hydrogen demand. While the details of the KWS are discussed in Section 5.1, this section highlights the ambiguities that currently hinder investment.

A high level of public support automatically increases ambiguity when compared to a path based on inherent economic sustainability.[5] And when multiple actors and interdependencies are required for success, it becomes even more difficult to attract private capital.

DEPENDENCE ON SUBSIDIES INCREASES AMBIGUITY FOR INVESTORS.

Additionally, from an operational perspective, competing technologies often offer techno-economic advantages over hydrogen. Where electricity imports, battery storage, and demand-side flexibility are available and economically viable, they will tend to displace hydrogen in the electricity market. At the same time, increased industrial demand for hydrogen can drive up costs for its use in the power sector.

Before the energy crisis, natural gas was considered a risky energy source. During the war, security of gas supply became genuinely ambiguous, due to insufficient diversification – until alternative import routes were established. The future availability and price of hydrogen will also be subject to ambiguity. As long as there is no liquid global market with stable, predictable prices, hydrogen use will remain dependent on subsidy mechanisms – which, due to their financing needs, are themselves inherently ambiguous.

As a result, when dealing with ambiguity, only those hydrogen use cases can be considered economically viable where no alternative decarbonisation options are available at relevant scale.

### The Future of the Bidding Zone

Currently, the transmission capacity of the electricity grid is insufficient to physically implement the market results of a single bidding zone without intervention. Transmission system operators (TSOs) use redispatch measures to maintain system security while implementing the market outcome as effectively as possible. These measures incur external costs, including redispatch costs,

[5] There are numerous examples of ambiguity in support schemes. For instance, photovoltaic deployment was significantly reduced between 2011 and 2013 due to sharp cuts in subsidies. More recently, following the 2023 ruling of the Federal Constitutional Court on the federal budget (the so-called 'Climate and Transformation Fund ruling'), the purchase premium for electric vehicles was withdrawn at short notice and the scope of the power plant strategy was significantly reduced.

which have triggered political debate about the future of the bidding zone at both German and European levels.

Ambiguity about the future configuration of the bidding zone complicates investment planning, as it is unclear in which market area future revenues will be generated. The political discussion is accompanied by a series of official and unofficial assessments, such as the EU Bidding Zone Review. A rapid and extensive expansion of the grid would make it more likely that the single bidding zone can be maintained. However, the pace of grid expansion is highly uncertain. If significant delays occur, the costs of maintaining a single zone may continue to rise.

Should hydrogen be required for redispatch in the future, this could lead to cost burdens that are no longer socially or economically justifiable. For example, if electricity consumption for charging electric vehicles, heating with heat pumps, or filling storage systems in a congested region is incentivised by high wind power generation and strongly negative prices in a surplus region, very high redispatch volumes would be needed to implement the market result. This would entail additional investment costs compared to having a separate bidding zone.

If hydrogen is also used for redispatch, operating costs may reach levels that are difficult to justify. For instance, Prognos (2022) assumes a hydrogen market price of EUR 140/$MWh_{th}$ in 2040. With a gas turbine efficiency of 40%, this translates into short-term electricity generation costs of EUR 350/$MWh_{el}$. While electricity consumption in this case is incentivised by negative prices, the actual cost of electricity would be EUR 350/$MWh_{el}$. These costs would have to be recovered through grid tariffs or public budgets.

Despite strong political motivation to maintain the current bidding zone configuration, these techno-economic realities create ambiguity for investors. While 2040 may seem distant, from the perspective of capital-intensive power plant investments, it lies well within a standard refinancing period.

This discussion is not intended to argue in favour of a bidding zone split. A split would in turn create ambiguity about further future reconfigurations, and thus contribute to investment uncertainty as well. The point here is simply to illustrate that the uncertainty surrounding the future of the bidding zone understandably contributes to investment restraint – and that it is the role of policymakers to establish reliable framework conditions that enable investment (see Section 6.1.2.)

### Take Aways

In this section, we have discussed several sources of ambiguity that contribute – to varying degrees – to the current reluctance to invest:

- Political target-setting, as illustrated by the coal phase-out
- Interventions in market dynamics and price formation, with examples from the electricity market and the EU ETS
- Structural dependence on subsidies, due to the lack of economically sustainable business models, as in the case of the hydrogen market
- Lack of political resolution, as illustrated by the ongoing uncertainty over the future of the bidding zone

In Chapter 6, we discuss strategic approaches to managing ambiguity more effectively. The overarching goal should be to establish sustainable framework conditions that enable market-based investment.

It is important to keep in mind, however, that market participants invest in response to scarcity. Political uncertainty often arises in the absence of overcapacity. From a welfare perspective, what matters most is achieving the right balance of generation capacity and flexibility options – while taking into account the physical transport capacities within the internal electricity market.

# 3 Criteria for the Sustainable Integration of the Energy Policy Triangle

SUSTAINABLE SECURITY OF SUPPLY

Ensuring security of supply at low cost through market-based incentives is the most sustainable path to promoting societal welfare.

The energy policy triangle has long served as a guiding framework in energy policy discussions. Achieving a balance between security of supply, environmental sustainability, and economic efficiency is essential for the sustainable development of the energy system. In practice, however, one of the three dimensions is often prioritised due to short-term circumstances – which in turn leads to the need for corrective action in the medium term. These foreseeable corrections increase ambiguity for market actors and may discourage investment.

In contrast, a sustainable market design aims to integrate all three goals in a balanced way across all concrete implementation steps. Ideally, this allows for the creation of reliable framework conditions, enabling market participants to invest with greater predictability.

The three goals – security of supply, environmental sustainability, and economic efficiency – are intentionally defined in abstract terms, allowing them to be applied to new and evolving challenges. However, for practical decision-making, these goals need to be operationalised. In addition, there are energy policy frameworks that require complementary criteria in order to successfully design and implement measures and instruments.

At first glance, the focus may fall on the conflicts and trade-offs between the goals. However, as we will show, the three dimensions also overlap and, in some cases, mutually reinforce one another. Their integration is therefore essential for a sustainable market design.

Before turning to the goals in more detail, we first outline the core functions of a sustainable market design.

INFOBOX: TASKS OF MARKET DESIGN

The role of a sustainable market design is to establish a regulatory framework that enables a secure electricity supply at the lowest possible cost and with the least environmental impact. These objectives are achieved by incentivising goal-aligned behaviour through the design of rules and market mechanisms.

To implement this sustainably, the core functions of market design can be distinguished across two time horizons:

- SHORT TERM: In day-to-day system operation, the task of market design is to match supply and demand. When the supply and demand curves intersect, a market-clearing price emerges, which reflects current market conditions and can signal scarcity. On the supply side, scarcity may arise due to limited dispatchable capacity, which is reflected in situational price spikes. On the demand side, scarcity manifests in limited elasticity, i.e., limited ability to increase or reduce demand. Low or even negative prices signal a scarcity of demand expansion. High prices signal a scarcity of demand-side reduction. An appropriate level of competition between supply-side expansion and demand-side flexibility mitigates excessive price spikes and reduces the risk of market power abuse.
- LONG TERM: In the long run, scarcity signals incentivise cost-efficient capacity expansion (e.g., new power plants) and increased demand-side flexibility, provided there are no significant barriers to market entry.

A sustainable market design requires predictable framework conditions. Low levels of ambiguity and minimal administrative hurdles (e.g., permitting for new power plants) are essential to ensure that investments can be realised in a timely manner.

In this context, market design can be clearly distinguished from support scheme design:

- Support schemes typically require frequent adjustments, which increase ambiguity for investors.
- Unlike market design, support schemes involve a redistribution of risk – usually away from one technology and onto other technologies or society as a whole.
- These interventions in market allocation often create external effects, which can manifest in various ways.

Ideally, support schemes should be temporary, for example until an externality has been internalised or a technology reaches commercial maturity. In contrast, market design should be permanent and robust, requiring as few and as minimal adjustments as possible.

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A sustainable market design should be capable of providing goal-aligned incentives both during the current transformation phase and in the long term. The design elements of the market framework must therefore meet a broad range of criteria in order to be fully fit for purpose.

In the following, we discuss the operationalisable criteria along the three core objectives of the Energy Policy Triangle.

## 3.1 SECURITY OF SUPPLY

To address the overarching objective of security of supply in a sustainable manner, we apply a broad set of assessment criteria.

### Effectiveness

Security of supply is effectively ensured when there is a market-clearing point between the supply and demand curves – that is, when consumers with high willingness to pay (i.e. relatively inelastic demand) are able to meet their electricity needs. In contrast, flexible consumers with high price elasticity attach lower value to electricity consumption in a given situation and are able to reduce or shift their demand.

This applies, for example, to electric vehicle charging: some consumers are willing to shift charging from 19:00 to 03:00 if their next planned trip is not until 08:00. The ability and willingness to shift demand contributes significantly to system stability and security of supply.

We explore the role of flexible consumers in more detail in Section 4.5, which focuses on the market-based organisation of security of supply.

### Target Accuracy

A stricter interpretation of the effectiveness criterion is target accuracy. This criterion overlaps to some extent with the objective of economic efficiency. For example, a large supply shortfall is less acceptable than a small one. The same logic applies in the case of oversupply: a high level of overcapacity weakens the effectiveness of a measure, as an overbuilt system is not sustainable in the long run. Sooner or later, political or societal actors are likely to call for interventions to reduce the costs associated with overcapacity.

In this sense, system costs implicitly affect the effectiveness dimension of supply security. The more precisely an incentive system addresses security of supply, the more sustainable it becomes.

### System Security

A further dimension of security of supply is system security. While supply security formally refers to the bidding zone as a whole, system security addresses regional or local supply adequacy within a bidding zone. This means, on the one hand, that grid capacity must be sufficient, and on the other hand, that the geographical distribution of generation capacity must allow for secure grid operation – including the provision of ancillary services at all times.

System security falls primarily within the regulatory domain, and is therefore organised differently from the market-based incentives that are the focus of market design. For this reason, we do not examine system security in the same depth as market-based mechanisms in this study.

### Energy Security

Another important dimension of security of supply is energy security, which refers to the reliable availability of primary energy carriers. This issue came to the forefront of energy policy during the energy crisis triggered by Russia's war of aggression against Ukraine, after having been largely absent from the political agenda for many years. The costs of having neglected this dimension became tangible during the crisis, making it a clear example of why a sustainable market design must address all relevant dimensions of supply security.

However, energy security should not be equated with calls for energy autarky, which often lead to disproportionately high costs and other forms of uncertainty. The example of Germany's dependency on Russian gas imports illustrates how a one-sided dependency can create unpredictable ambiguity. At the same time, the current debate in the United States on restricting LNG export licences shows that diversification is generally a prudent strategy – particularly when dealing with trading partners whose geopolitical interests diverge.

In principle, international economic cooperation can help increase the likelihood of peaceful relations. However, this is best achieved through diversified supply sources of primary energy, so that risks of supply disruptions remain manageable and calculable.

## 3.2 ENVIRONMENTAL SUSTAINABILITY

The current transformation of the energy system is primarily aimed at enhancing environmental sustainability. The EU Emissions Trading System (EU ETS), for example, is a targeted instrument designed to incentivise the decarbonisation of electricity generation. In contrast, the current debate on market design reform has been primarily driven by concerns over security of supply.

The overarching objective is to develop a sustainable market design that integrates supply security with the requirements of the energy transition, using a cost-efficient system of incentives.

The measures discussed in this study are therefore rooted in the broader goal of environmental improvement. However, they are not intended to directly increase environmental performance. Rather, they aim to establish the framework conditions under which environmental sustainability – for example through the decarbonisation and flexibilisation of system components – can be achieved in a sustainable and frictionless manner.

### Decarbonisation

The overarching objective of the energy transition is decarbonisation. Incentive mechanisms that contribute to direct or indirect emissions reductions are therefore assessed more favourably under the criterion of environmental sustainability than those that create friction for decarbonisation.

This may be the case, for example, if policies reinforce fossil path dependencies or increase investment risks for low-emission technologies.

### Integration of Renewable Energy Sources

The integration of renewable energy (RE) plays a central role both in the transformation phase and in the long-term development of the electricity market design.

Maximising the share of renewable electricity used to meet demand reduces the need for fossil fuels and thereby lowers greenhouse gas emissions. In this regard, the design of incentives that enhance system flexibility is generally considered positive for environmental sustainability.

Flexibility also intersects with the goals of supply security and economic efficiency. A more flexible system is more secure, as it improves the ability to match supply and demand. At the same time, a flexible system is also more economically efficient, as it strengthens competition between supply- and demand-side technologies. This reduces overall system costs and mitigates the exercise of market power.

## 3.3 ECONOMIC EFFICIENCY

Economic efficiency encompasses a range of factors that collectively contribute to the welfare-enhancing organisation of the energy system. (See also the info box on the tasks of market design at the beginning of this chapter.)

### Efficiency

In the context of the energy policy triangle, the third objective is sometimes referred to as affordability. However, this formulation is, in our view, too narrow. By contrast, the concept of economic efficiency refers to the design of a market-based framework that incentivises a variety of goal-aligned behaviours through an appropriate system of incentives. These incentives improve overall system efficiency, and thereby lead – as a consequence – to affordable prices.

Affordability alone cannot be a meaningful policy goal, as even in a system with high total system costs, regulatory price controls could impose artificially low retail prices. In such cases, prices would appear affordable, but the costs would be shifted, for example, to the federal budget or support schemes, without market signals playing a meaningful role in influencing behaviour. Such cost shifting typically results in externalities and market distortions, which ultimately reduce societal welfare.

The concept of economic efficiency therefore primarily refers to a market order characterised by intense competition and mechanisms that incentivise low total system costs. However, for these effects to materialise, several preconditions must be met, which we discuss in the remainder of this section.

### Market Segmentation

It is sometimes argued that different mechanisms are needed to incentivise investments in new assets and to maintain existing capacity. However, such segmentation introduces a centrally planned logic into the market. From the perspective of demand fulfilment, it makes no difference whether electricity is generated by a new or existing plant. An energy unit has a homogeneous utility and should therefore have the same value, regardless of its origin.

Segmenting the market implies the assumption that comprehensive knowledge exists regarding all incentives and system requirements, making fine-tuned control theoretically possible. In practice, however, such segmentation of both the market and its incentive structure inevitably leads to distorted signals, which in the medium to long term increase total system costs.

### Barriers to Market Entry

Competition should not be limited to existing market participants and established technologies. It must also allow for future market entrants. However, regulation tends to address the current structure of the market, inherently acting as a barrier to entry. For the principle of economic efficiency to unfold, it is essential that barriers to entry are kept low – particularly for new competitors and innovative technologies.

Only under these conditions can the incentive structure ensure efficiency. Moreover, it ensures that the objectives of supply security and environmental sustainability can be achieved at consistently low total system costs, which ultimately results in affordability.

A sustainable market design must therefore remain open to positive uncertainty in the form of technological innovation. This is especially relevant in transformation phases, where incentives should enable the emergence of more cost-efficient and goal-aligned solutions. In this sense, market openness and innovation-friendliness are essential preconditions for a sustainably efficient market design.

### Market Power

Regulatory frameworks that facilitate the emergence or exploitation of market power conflict with the principle of economic efficiency. Dominant market players may use short- and long-term strategies to influence prices and access to resources, and even to shape market structures and design in their favour (see Infobox: Regulatory Capture in the section on political-economic criteria).

Such influence can also result in regulatory barriers that discourage market entry by new competitors and limit innovation. These are often reinforced by distorted political-economic Incentives that create advantages for incumbents while raising the entry threshold for alternative or more efficient solutions.

#### Avoiding Path Dependencies

A sustainable market design aims to keep the technological solution space as open as possible, enabling market actors to respond flexibly to evolving conditions. As a result, regulatory path dependencies should be avoided, as they tend to constrain future options and restrict the adaptability of the system.

Path dependencies also create long-term cost risks when previously chosen pathways turn out to be technologically or economically unsustainable. Regulatory frameworks, by nature, tend to orient themselves around existing companies and technologies, whereas innovations typically emerge from areas of uncertainty. This makes it inherently difficult for regulation to fully anticipate future needs.

A flexible and open market design allows for market-based adjustments and reversibility, making it better equipped to incorporate technological innovation as it arises.

## 3.4 POLITICAL-ECONOMIC CRITERIA

The practical feasibility of implementing market design concepts within existing societal, political, and regulatory frameworks depends critically on a set of political-economic criteria. It is during the process of legislative and institutional implementation that it becomes apparent whether these concepts are realised in line with the previously discussed principles – or whether key elements become distorted.

### Institutional Frameworks

A central factor for implementation is the institutional architecture of the energy system. This includes legal, administrative, and organisational structures at the national (federal and state) and European levels.

Legislation in Germany is drafted by ministries, passed by the Bundestag with input from the Bundesrat, and subsequently implemented and administered by responsible authorities such as the Federal Network Agency (BNetzA) or the Federal Environment Agency (UBA). Moreover, many of the policy instruments discussed in this study are subject to EU state aid clearance, which adds an additional layer of procedural and legal complexity.

Beyond administrative responsibilities, the financing structure of individual measures also plays a crucial role. Costs may be borne directly by electricity consumers through price components, levies, surcharges, or network charges, or financed through tax revenues at the federal, state, or municipal level. These different cost allocations imply different legal and regulatory responsibilities and require coordination across institutions.

For example, the promotion of renewable energy is no longer financed through a surcharge on the electricity price, but rather via the federal budget. However, the variability of the EEG account (Renewable Energy Act account) is difficult to predict, creating new challenges for fiscal planning and the design of renewable energy support schemes. As of now, an additional €8.7 billion in federal funding will be required in 2024 compared to what was forecast during the budget negotiations in autumn 2023.

The institutional framework is a crucial criterion, as all developed concepts must pass through a series of stakeholder negotiations during implementation. The more complex the measure, the greater the risk that its original purpose will be diluted – and that distorted political-economic incentives may emerge during the process.

### Compatibility with the European Framework

A particularly important institutional requirement that deserves explicit attention is compatibility with the European internal market. On the one hand, this includes compliance with EU State Aid Guidelines (2022). On the other hand, compatibility with the EU framework overlaps significantly with the criteria of economic efficiency.

- In the short term, EU-level requirements may appear as a regulatory friction, as it would often be administratively easier to implement measures solely in the national interest.
- In the longer term, however, the European legal and institutional framework serves to orchestrate the diversity of interests across Member States – particularly in the context of ensuring a well-functioning internal market, which is one of the key preconditions for Europe’s global competitiveness. From this perspective, the challenge lies in reconciling regulatory consistency with the diversity of national approaches, in order to realise the long-term benefits of a truly competitive European market.

From a German perspective, the functioning of the internal market is of overriding importance. Beyond the general advantages for the German economy, it is especially relevant in enabling the integration of renewable energy sources, which benefits greatly from cross-border electricity trade and system balancing.

In times of crisis, the human reflex is often to retreat and aim for autarky. However understandable, this response can lead to long-term limitations and costs. In fact, it is precisely in times of crisis that the added value of cooperation and openness becomes clear – contributing to Europe's resilience and agility.

The EU's collective response to the gas crisis, including the reorganisation of gas flows, provides a compelling example of this. Translating this spirit of cooperation into an open, innovative, resilient, and competitive Europe should therefore be seen as a guiding principle of every (energy) policy measure.

From an institutional perspective, EU compatibility may often represent an additional layer of complexity. But over the long term, it is precisely this compatibility that enables the full value of a sustainable and competitive market structure to materialise – especially in times of stress, when the benefits of efficiency and resilience become most apparent.

### Susceptibility to Political Influence

Another relevant implementation aspect of energy policy measures is their susceptibility to political influence. All societal stakeholders have a legitimate interest in contributing their expertise and communicating their needs. From a policymaking perspective, however, it is not always easy to distinguish between legitimate, evidence-based requirements and claims driven by corporate interests whose realisation would come at a cost to society – often referred to as rent-seeking[6]).

### INFOBOX: REGULATORY CAPTURE

Policymakers and public authorities act in the public interest, but they depend on information from market actors to design effective policies. This naturally creates informational asymmetries between policymakers on the one side and companies or interest groups on the other. For instance, former political staff often transition into industry associations or lobbying roles, allowing economic interests to be communicated in a politically accessible and trusted format.

However, when this communication overemphasises private interests, and policymakers lack the time or capacity to critically assess the information, policy measures may end up favouring individual market actors rather than the public good.

These forms of political influence can lead to market distortions, welfare losses, and negative environmental outcomes. In the long run, there is a risk of eroding public trust in democratic processes and institutions.

One way to reduce the susceptibility to political influence is to design instruments that require as few regulatory levers as possible in order to be effective. This typically means strengthening market-based structures and allowing competitive forces to operate, rather than relying on regulatory micromanagement. Every regulatory lever must be readjusted as conditions change – and each adjustment creates a new opportunity for influence and increases ambiguity for market participants.

For this reason, regulatory approaches are often helpful and appropriate in the initial design phase, when political and public attention is high. But as political and media focus fades, interest-driven influence may gradually gain traction. Market-based instruments also unfold their full competitive potential over time. Even if short-term scenario comparisons show no significant cost differences between regulatory and market-based options, distorted political-economic incentives and competitive dynamics usually pull in opposite directions over the long term.

This is why some companies may have a strategic interest in increasing regulatory complexity: on the one hand to shield themselves from competition,

[6] See e.g. Krueger (1974): The Political Economy of the Rent-Seeking Society.

market entry and innovation, and on the other to leverage their specialised knowledge to secure more favourable conditions.

### Susceptibility to Misaligned and Distorted Political-Economic Incentives

One of the core functions of market-based organisation is to enable a multi-dimensional allocation of resources, with the aim of ensuring energy supply as efficiently as possible, while complying with regulatory constraints. The outcome of such allocation processes is, by nature, hard to predict – there is an inherent degree of uncertainty. It is the task of private companies to manage this uncertainty as part of their entrepreneurial responsibility.

Elected political decision-makers, by contrast, tend to be risk-averse, as they place high value on their public reputation. They generally seek to avoid the impression that they are not acting in a responsible and socially acceptable manner. Due to similar institutional dynamics, this risk aversion is also common among civil servants and regulatory staff, who seek to avoid personal or institutional exposure.

When measures are designed through regulation, there is typically no single optimal solution, but instead trade-offs – e.g. between the cost of a measure and its scope. Political and regulatory actors aim to allocate public resources responsibly. However, it is in human nature to make decisions not only based on public benefit, but also under consideration of personal risk and incentives.

If a measure turns out to be over-dimensioned, there are usually no personal consequences for decision-makers, as the cost is spread across taxpayers.[7] This tendency is reinforced when costs are financed through non-transparent special funds or off-budget instruments. If, on the other hand, a measure turns out to be under-dimensioned – and supply security is jeopardised – the personal reputational risk for decision-makers is potentially high. From this perspective, a certain degree of risk aversion is understandable. Yet from a societal point of view, it constitutes a misaligned political-economic incentive: it leads to market distortions and higher system costs in the long run.

These misaligned and distorted incentives typically result in oversized interventions and a narrow technological solution space. The perceived effectiveness of a measure increases, while the discomfort of uncertainty is

[7] The author Nassim Nicholas Taleb discusses the effects of such distorted incentives in detail in his book “Skin in the Game” (Taleb, 2018).

reduced. But in doing so, innovative and cost-efficient solutions are often sidelined, ultimately lowering overall societal welfare.

Once again, a market-based framework – which leverages decentralised knowledge and addresses individual preferences – is more likely to produce welfare-enhancing outcomes from a societal perspective.

### Social Acceptance

The example of the German Building Energy Act (Gebäudeenergiegesetz) demonstrated that even generous financial support for policy measures does not automatically translate into widespread acceptance. When policies affect personal freedoms or lifestyle choices, they tend to attract high levels of media attention and societal debate.

Even if such measures include safeguards to protect households financially, limitations on choice can still provoke resistance from parts of the population. There is growing evidence that acceptance increases when policies are incentive-based rather than restrictive – for instance, through nudging approaches that combine transparent information with targeted support.

Such approaches are typically based on:

- clear communication of economic benefits and cost risks associated with proposed solutions, and
- financial incentives rather than obligations.

Individual preferences are complex and diverse. Many people react strongly when they perceive their preferred way of life to be constrained. This is not new: a similar pattern was observed when seatbelt use in cars became mandatory in Germany in 1976.

In the short term, some individuals may prefer to bear financial disadvantages rather than change established habits. In the long term, however, economic incentives tend to prevail.

# 4 Background: The Market-Based Organisation of Security of Supply

INCENTIVES ORCHESTRATE COMPLEXITY

Market-based incentives and information about individual preferences are essential prerequisites for ensuring energy supply at the lowest possible cost.

This background chapter explores how markets function in principle and, more specifically, how they can be used to safeguard security of supply in the electricity sector. Together with the criteria discussed in the previous chapter, this forms the foundation for the evaluation of capacity mechanisms in the next chapter, with a view to designing a sustainable market framework.

We begin by discussing the societal role of market-based organisation. We then examine how incentives operate within such frameworks and how they influence decision-making. Next, we shift focus to the more technical aspects of security of supply and merge them with insights from market organisation to address the specific challenges of a dynamic, renewables-based electricity system. Finally, these insights provide the basis for a dedicated discussion on the crucial role of flexible consumers.

## 4.1 THE ROLE OF A MARKET-BASED ORGANISATION

The electricity system plays a special role in society, as it forms a foundation for societal welfare. Its functioning brings together expertise from a range of disciplines, making it an exceptionally complex system. Its physical foundations are self-evident. The political dimensions of the energy sector are part of everyday discourse. The legal framework provides a constitutional basis. And then there is the invisible hand of the economic incentive system, which orchestrates the interaction of market participants and minimises overall system costs.

There are many different perspectives on this form of market-based organisation, often marked by varying degrees of trust. This may be due, in part, to misconceptions about how such systems actually work. This section therefore takes a step back to explore some fundamental aspects of how market-based organisation functions, along with the role of the academic discipline of economics.

At first glance, this may appear overly theoretical for an applied study focused on a concrete policy question. However, from our perspective, a robust understanding of market-based organisation is a necessary foundation for any meaningful assessment of market design. This section is therefore intended to lay the groundwork for the discussions that follow.

### Common Criticism of a Market-Based Organisation

In neoclassical economics, a number of simplifying assumptions are made in order to model economic relationships in a quantitative and analytically tractable way. These assumptions are occasionally criticised in public discourse, and such criticism is sometimes used to reject market-based approaches altogether.

However, this often involves two logical fallacies:

- First, a narrow category of economic methods is generalised to represent the entire field of economics.
- Second, the analytical tools used to describe market processes are mistaken for the actual functioning of markets themselves.

Neither of these fallacies is logically sound. This section addresses these misconceptions and clarifies what, from our perspective, market-based organisation is really about.

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#### INFOBOX: ASSUMPTIONS OF NEOCLASSICAL ECONOMICS

Neoclassical theory uses a set of assumptions to describe market dynamics through quantifiable models. These models rely on the concept of the Homo Economicus – a model of a rationally acting individual. Key assumptions in neoclassical economics include:

- RATIONALITY: Individuals act rationally in order to maximise their utility. Rationality in this context means using available information to make the best possible decisions. Utility is not limited to financial profit but refers more broadly to the achievement of personal goals.
- PERFECT INFORMATION: All market participants are assumed to have full access to all relevant information required to make optimal decisions. In other words, the model abstracts from uncertainty and information asymmetries.
- STABLE PREFERENCES: Preferences are assumed to be consistent over time and unaffected by external influences.

- MARGINAL ANALYSIS: Individuals make decisions by comparing the marginal benefits and marginal costs of the next possible action. This is how they maximise their individual utility.
- MARKET EQUILIBRIUM: Neoclassical theory assumes that efficient market equilibria exist – states in which supply and demand balance, leading to optimal resource allocation.

These assumptions are simplifications, designed to reduce the complexity of real-world market processes. Such simplification is a necessary feature of scientific modelling. However, it also means that models have limitations in terms of their explanatory power. As in all scientific disciplines, it is the conscious and transparent handling of these limitations that determines the quality of the analysis and the relevance of resulting policy recommendations.

There are good reasons why neoclassical economics has emerged as one of the most influential schools of thought in the field of economics. At the same time, there are equally valid reasons why complementary schools have developed alongside it. In the following section, we outline both the benefits and limitations of the neoclassical approach.

### Benefits and Limitations of Neoclassical Economics

Neoclassical models provide a framework for analysing complex interactions:

- ANALYTICAL TOOLS: Thanks to its simplifying assumptions, neoclassical theory offers a clear and structured analytical toolkit that allows for a broad – though not unlimited – range of research questions to be examined in a methodologically rigorous way. Its core principles of price formation enable a systematic investigation of how markets function, using supply and demand curves.
- ANALYSIS OF MARKET RESPONSES: Based on this market understanding, neoclassical models allow for the examination of how markets respond to changes in fundamental conditions. For example, they can help estimate how electricity markets might react to changes in fuel prices, $CO_2$ pricing, or the expansion of renewable energy.
- WELFARE ENHANCEMENT: The rigorous analysis of such interdependencies makes it possible to formulate policy recommendations aimed at improving societal welfare. For instance, neoclassical models can help identify market imperfections and frictions – the removal of which, e.g. through the internalisation of externalities

such as $CO_2$ emissions, can increase overall market efficiency for the benefit of society.

Despite their many strengths, neoclassical models face important limitations, particularly due to the restrictive assumptions they rely on:

- RESTRICTIVE ASSUMPTIONS: Core assumptions such as perfect information or fully rational behaviour significantly limit the explanatory power of neoclassical models, particularly in the context of complex and dynamic market developments.
- NEGLECT OF UNCERTAINTY: The assumption of complete information abstracts from uncertainty, which is a critical condition for decision-making in real-world contexts.
- MARKET DYNAMICS AND TECHNOLOGICAL INNOVATION: Neoclassical models typically focus on market equilibrium, which limits their ability to reflect dynamic developments. Moreover, their ability to incorporate innovation processes is extremely limited.
- SOCIAL ASPECTS: Social, cultural, and ethical factors often play a significant role in both economic and political decision-making. These dimensions are, at best, only rudimentarily captured in neoclassical models. Nevertheless, the core objective of neoclassical analysis is to increase societal welfare – which, if supported by effective redistribution mechanisms, can benefit all segments of the population.

These limitations do not undermine the value of neoclassical models. Rather, they underscore the need for careful application and thoughtful interpretation of results.[8]

ELECTRICITY MARKET MODELS ARE BASED ON EXPLICIT AND IMPLICIT ASSUMPTIONS THAT MUST BE CONSIDERED WHEN USING AND INTERPRETING THE RESULTS.

A prominent example of how neoclassical tools are applied in practice are electricity market models, which are widely used to quantify market processes. Such models are particularly well suited for short-term analysis, for example when operating under static assumptions – such as an existing power plant fleet. In these cases, the available information generally reflects real-world conditions with sufficient accuracy. Both fundamental modelling and statistical methods are highly effective at describing dispatch

[8] Due to the demanding assumptions placed on users of neoclassical models and their limited explanatory power with regard to real-world dynamics, complementary economic approaches have emerged – such as institutional economics, behavioural economics, and game theory – to shed light on selected aspects of market behaviour.

behaviour and price developments in the near term, precisely because uncertainty about the necessary input parameters is relatively low.

However, the quality and certainty of available information change fundamentally when such models are applied to long-term projections. In such cases, a wide range of assumptions must be made regarding future developments in fuel and $CO_2$-prices, capital and investment costs, available technologies, and – crucially – consumer preferences. In a static world without major technological change, investment models can still reasonably approximate future developments. However, their reliability diminishes significantly when uncertainty increases, and structural change becomes more likely.[9]

Even in such cases, model-based analyses provide substantial value. They demonstrate that, based on currently available technologies and the present state of knowledge, the transformation of the energy system is feasible. However, this does not imply that model results can or should be interpreted as forecasts. Rather, they are scenario-based explorations of very specific questions, built on highly restrictive assumptions.

These models place high demands on their users and on readers of the results. Human beings have a strong need for certainty, which can lead to a tendency to unconsciously interpret quantified results as predictions. In reality, models simply translate assumptions into results, using highly complex mechanical or mathematical logic. It is common for specific outcomes of model-based studies to be singled out and criticised as "unrealistic." For example, the latest long-term scenarios published by the BMWK show no deployment of home battery storage systems, despite significant real-world uptake.

But the question the model answers is different: "What is the most cost-efficient way to meet demand, given the predefined assumptions?" These assumptions include not only future developments of key fundamentals (e.g. fuel prices), but also the neoclassical assumptions discussed earlier, such as perfect foresight and rational behaviour. In such a model world, home battery storage systems may simply not be part of the cost-minimising solution.

Discrepancies between model outcomes and observed behaviour in the real world can in fact offer important insights. They can point to real-world conditions that differ from the modelled world – for example, due to additional restrictions

[9] If, for example, integrated electricity and heat market models take into account only currently widespread technologies when modelling long-term investment decisions, this typically results in high hydrogen demand and thus high system costs. By contrast, if emerging innovations – such as developments in heat pumps, electricity and heat storage technologies, and various geothermal technologies – were taken into account, the results could differ significantly, potentially leading to much lower decarbonisation costs and, in the long term, substantially lower total system costs. However, innovations are, by their very nature, unknowns that cannot be adequately reflected in long-term planning processes.

or behavioural patterns not captured by the model. This can lead to two responses:

- First, one can refine the model to better reflect the real-world context by adding additional constraints.
- Second, the insights from the model can inform adjustments to the real-world policy framework, in order to align incentives in a way that promotes greater societal welfare.

In this sense, the burden of interpretation lies with the user. In many cases, users expect a forecast. But no neoclassical model can provide that. These models answer specific questions based on a defined set of assumptions. To make the results useful for real-world application, a careful translation is required – one that involves deep understanding of both the inner logic of the model and the real-world context in which the results are applied. It is the difference between these two perspectives that can yield new insights.

Moreover, the purpose and context of model use matter. Private actors may use economic models to align their assumptions about the future with their strategic decisions. In such cases, models can provide internal consistency.

However, when government actors use administratively defined model assumptions to impose binding regulatory decisions – such as technological mandates or restrictions on private-sector action – this takes on a very different character. It reflects a presumption of knowledge about the future, which limits the solution space and, in all likelihood, reduces overall societal welfare.

### The Functions of Market-Based Organisation

The discipline of economics attempts to describe market dynamics using scientific methods – yet this is not the same as market dynamics themselves. There remains a distinction between the map and the territory. Even empirical methods have their limitations, as real-world conditions are never perfectly comparable. Nonetheless, patterns emerge, which can be generalised – not to make precise predictions, but to identify causal relationships and key influencing factors, and to make them analytically useful.

The role of markets is sometimes simplistically described as a matter of resource allocation. But if the assumptions of neoclassical economics were fully met – perfect information, no uncertainty, no transaction costs – then markets would not be necessary. In such a world, allocation would be a complicated but predictable problem, and could be solved through central planning.

In reality, however, markets are needed precisely because they reveal information that would otherwise remain hidden. As discussed earlier in Section 2.3.1(see Infobox Information Asymmetries), the full characteristics of a transaction are often only revealed in the process of negotiation. These pieces of information do not pre-exist – they emerge from interaction. Markets are complex systems. And one of the defining characteristics of complex systems is emergence – the whole is more than the sum of its parts.[10] For this added value to emerge, competition plays a central role.

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### INFOBOX: THE ROLE OF COMPETITION

Competition is sometimes viewed critically – seen as something inhuman or unsustainable. This criticism often stems from a static perspective. From this viewpoint, markets are simply a tool for allocation, where one party gains what another loses. This logic follows the idea of a zero-sum game. From that angle, markets may appear unnecessary – something that could be replaced by central planning, which would be smoother and more socially just.

But there is another way to view competition. In this alternative perspective, competition is a discovery process. Through the incentives it orchestrates, competition creates the conditions under which valuable information emerges. In this sense, competition provides feedback – nurturing rather than destructive.

This view is more akin to the spirit of sport. An athlete who loses learns where to improve. There is a saying in sports: "You either win, or you learn." From this angle, there is no such thing as failure – there is always the chance to grow. With this mindset, competition becomes not a zero-sum game, but a positive-sum game.

In this light, competition becomes deeply human. Every child learning to walk falls – this is not failure, but feedback and motivation to try again. Sport would lose its appeal if medals were distributed according to a pre-defined allocation formula.

The possibility of failure is an essential part of any incentive system. It is precisely the feedback loops of competition that trigger progress. Through learning and continuous adaptation, markets enhance the resilience of both businesses and society as a whole.

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[10] Human consciousness, for example, cannot be explained by the properties of individual neurons. Consciousness is an emergent phenomenon that arises from the complex interactions between brain cells.

> Market design can therefore foster appropriate incentives by constructively incorporating risk. By contrast, subsidy-based systems shift risks away from market actors onto society, weakening the ability of businesses to adapt to uncertainty and change.
>
> The emergent qualities of economic competition cannot be replicated through central planning.[11] In fact, static allocation through planning does not reveal new information – it depends on information that only becomes visible through market processes.
>
> Nor can central planning replicate the pressure to innovate and improve that competition naturally produces.[12] Market-based competition, as a structured feedback system, becomes a foundation for innovation, productivity, and societal well-being.

A static view of markets as mere allocation mechanisms falls far short of capturing their full potential. From a dynamic perspective, the allocation task internalizes market feedback and distributes resources not only across sectors, but intertemporally as well. In this way, the incentive for innovation becomes a fundamental part of how markets function.

The allocation task in a complex system spans multiple dimensions that cannot be centrally captured or planned. The relevant information about skills, preferences, and resources of people and businesses is dispersed across society.

In electricity markets, companies have always had an informational advantage over regulatory authorities. Looking ahead, the increasing number of heat pumps, home batteries, and electric vehicles means that a growing share of system-relevant information will be held by private individuals. Only individuals themselves know their preferences regarding mobility, comfort, and the timing of their electricity consumption. Moreover, these preferences are not static –

[11] Market-based incentives foster competition and cooperative specialisation, for example through trade. Rather than merely redistributing what already exists (a zero-sum game), they enable value creation in the sense of a positive-sum game – generating added value through innovation and economic growth. For instance, technological progress in telecommunications not only led to new products such as smartphones, but also to new services and markets that improved living standards and created jobs.

[12] Throughout recent history, there have been repeated attempts to replace market mechanisms with computer-based planning systems. In the 1950s and 1960s, particularly in the Soviet Union, great hopes were placed in the use of computer models and cybernetic theories. However, the weaknesses of central planning became apparent through bureaucratic inefficiencies and distorted incentives, misallocation of resources, and – most notably – a lack of enabling conditions for innovation. Today, there is occasional debate about whether artificial intelligence could one day replace market mechanisms. Yet it is an inherent characteristic of information, incentives, and preferences that they are decentralised and constantly evolving – giving rise to unpredictable effects (emergence). For this reason, it remains likely that, for the foreseeable future, designing effective incentives through market-based frameworks will continue to be the most sustainable way to enhance societal welfare.

they continuously evolve over time. As a result, the coordination task is not deterministic, but inherently stochastic.

The vast amount of information that needs to be coordinated – and its inherent volatility – makes this coordination task a complex system.[13] By definition, complicated tools, such as electricity market models, are not capable of solving complex problems.

The desire to control complexity through regulation and planning approaches inevitably leads to a restriction of the solution space, thereby limiting individual preferences, innovation, and ultimately social welfare. What is needed is an agile, emergent form of organisation – one that can continuously internalise constantly changing information. This is the role that markets play. No central planning authority can fully replicate the decentralised processing of information or assume the necessary coordination task in its entirety.

These insights imply that market developments cannot be fully planned or controlled without incurring significant welfare losses. The goal of market design should therefore be to create a framework that enables the full use of both the information space and the solution space, allowing the desired outcomes to be achieved as cost-efficient as possible.

### The Market-Based Coordination Task in the Energy Sector

Power systems possess a range of inherent characteristics that create specific requirements for the market and regulatory framework. These characteristics can easily lead to an expansion of regulatory interventions, to the point where market mechanisms can no longer unfold their full potential. It is therefore helpful to examine the underlying system characteristics that give rise to these regulatory needs. This approach allows adjustments to the market design to be aligned more closely and purposefully with the fundamental requirements of the system.

[13] At present, competitive elements are often used to incentivise the deployment of specific technologies. However, there is a fundamental difference between 'competitive' and 'market-based' approaches. Market-based processes create incentives for emergent benefits such as innovation and value creation. Competitive processes, by contrast, involve the allocation of pre-defined solutions through rivalry, aiming to identify the most cost-efficient implementation. Yet the core allocation decision is already taken centrally, as the desired outcome – for example, a specific technology – is determined in advance. Competitive tendering may even hamper technological progress, as companies focus primarily on margin optimisation, sometimes accompanied by rent-seeking behaviour. As a result, genuinely innovative approaches may be inadvertently excluded from the solution space.

## INFOBOX: PROBLEM-SOLVING BASED ON FIRST PRINCIPLES

The concept of decision-making and problem-solving based on first principles goes back to Aristotle. He spoke of first principles as fundamental causes and axioms from which knowledge can be derived. Rather than approaching a problem through analogies or precedent, this method breaks complex challenges down into their most basic components and underlying truths. Conventional approaches often rely on implicit assumptions that constrain or distort the solution space. In the current debate about the future of electricity market design, for instance, it is worth asking: What is the actual underlying challenge for ensuring supply security through market mechanisms?

Instead of taking the political debate around new power plant construction as a given, a first-principles approach reveals that the core challenge is maintaining supply security. This reframing leads to a very different set of solutions than the question of how to incentivise new power plant investments. In this context, it is more effective – particularly in line with the goals of the Energy Policy Triangle – to base the search for solutions on fundamental principles rather than on assumed pathways.

A core challenge for ensuring supply security has always been the limited flexibility of demand – a constraint that continues to shape the trade-offs inherent in market design and regulatory interventions. This issue is amplified by the fact that electricity has traditionally been characterised by non-storability at economically relevant scales.[14]

A first-principles approach therefore leads us to ask how the requirements for market design and regulatory frameworks might change when these underlying characteristics begin to shift. Later in this chapter, we discuss the implications of increasing battery storage capacity and the growing share of flexible consumers. First, however, we focus on translating these basic principles into targeted incentive mechanisms.

The characteristic of non-storability can also be observed in other industries. For example, the service sector is structurally non-storable. The aviation and hotel industries rely on similar principles of economic optimisation as the electricity sector.

[14] Another key characteristic is the reliance on network infrastructure, which – due to the nature of a natural monopoly – necessitates regulatory approaches. These aspects are discussed in more detail in Section 6.1.2.

This theoretical model is referred to as peak-load pricing, as fixed costs are refinanced through higher prices during periods of scarcity, while pricing during normal demand periods is based on variable costs (i.e. short-run marginal costs). During holiday or conference seasons, airfare and hotel prices are significantly higher than during off-peak periods. Since demand exceeds available supply during these times, providers can charge higher prices, which in turn leads to a reduction in demand among price-sensitive or flexible consumers.

IN MARKETS WITH NON-STORABLE GOODS, INVESTMENTS RECOVER THEIR FIXED COSTS DURING PERIODS OF HIGH DEMAND.

However, this does not mean that only wealthy individuals can travel during peak times. By planning their trips well in advance, customers can secure lower prices than if they decide to travel spontaneously. In this sense, peak-load pricing also functions as a surcharge for spontaneity and inflexibility. Conversely, those who plan ahead or are flexible on short notice can take advantage of more affordable options. These incentives enhance overall welfare by avoiding economically inefficient overcapacity. The utilisation of services is optimised in line with individual preferences and willingness to pay, allowing investments to be operated economically.[15]

This logic can also be observed in the energy sector. Consumers and suppliers can hedge against short-term price spikes by securing more favourable prices on the long-term markets.[16] And if consumers are flexible on short notice, they can avoid high prices and take advantage of lower ones.

Due to the electrical requirement that supply and demand must always be balanced in the power grid, an incentive system is needed that can allocate consumption in real time. The balancing group system ensures that supply and

[15] At first glance, price-based differentiation in consumption may appear to have socially undesirable side effects. However, the key question is whether there are alternative mechanisms that are fairer and more conducive to societal welfare.

The willingness-to-pay principle creates incentives for expanding supply when demand arises. Without this price signal, the available supply would be smaller and would have to be allocated through alternative mechanisms. In socialist systems, allocation often depends on implicit power structures (such as nepotism), which likewise do not serve the public interest.

Moreover, price-based allocation prevents overcapacity, enabling investments to be self-sustaining. If overcapacity were to be maintained, it would need to be financed through price-exogenous transfers – typically borne by the general public. In such cases, non-travellers would effectively subsidise the consumption of travellers. As a result, seemingly social policies would lead to non-transparent and non-causal redistribution – ultimately at the expense of those who may not be able or willing to travel in the first place.

In addition, central planning – by assuming knowledge that cannot realistically be held – often leads to overcapacity and shortages in other areas, as decentralised information and preferences cannot be used in the allocation process. These cumulative misallocations reduce overall societal welfare, as individual needs are not adequately addressed, and additional costs arise at the system level. Taking these interdependencies into account, price signals represent the most effective and fairest means of increasing welfare.

[16] We define long-term markets as all market segments capable of providing hedging against market risks. This includes, among others, exchange-based trading and bilateral trading of hedging products, as well as self-generation and demand-side flexibility.

demand are planned in alignment, and that any deviations from the schedule are costed appropriately via the balancing energy system. This allocation creates the incentive to remain adequately hedged on the long-term markets in order to avoid additional costs from higher short-term prices on the spot market or in the balancing mechanism.

In the following section, we will discuss in more detail the economic effects of incentives. The role of long-term markets and their incentive effects are addressed in greater depth in Sections 5.6 and 6.2.

## 4.2 THE EFFECT OF INCENTIVES

In the previous section, we touched on the role of incentives in the context of market-based coordination and complexity. In this section, we explore in more detail how incentives orchestrate the behaviour of market actors. In everyday language, the term incentive is sometimes used synonymously with subsidy. Here, we refer specifically to the effect of price signals.

As we saw in the discussion on misaligned and distorted incentives in Section 2.3.1, even well-intentioned actors may be incentivised – due to the surrounding framework – to behave in ways that contradict societal objectives. Incentives, however, can also have a constructive effect if the framework conditions are well-designed. A target-oriented market design aligns private and individual incentives in such a way that they contribute to an increase in societal welfare.

There are many forms of incentive effects, which can differ depending on the cultural background and individual experience of an organisation or person. Some actors are motivated by the ambition to become market leaders. Others are driven by the desire to avoid failure. There are risk-takers and risk-averse actors. Some strive for innovation; others are driven by environmental goals or social impact. But regardless of the nature of these preferences, they all respond – consciously or unconsciously – to price signals as they pursue their respective objectives.

High prices attract market participants to invest and take on risk in the pursuit of higher profits. Price volatility indicates the level of risk associated with such investments. As a result, risk-averse actors may be deterred, while risk-tolerant actors may benefit from higher profit margins. The competitive response to high prices typically causes them to fall to an equilibrium level, which benefits consumers – introducing a social dimension to the dynamic.

### Completeness of the Price Signal

For the allocation of resources via price signals to generate a positive welfare effect, those signals must be as complete as possible. In terms of first principles, this means, among other things, that externalities should be fully internalised.

#### INFOBOX: MARKET DISTORTIONS AND EXTERNALITIES

Market distortions arise, among other things, from external interventions in market processes or from externalities that lead to a misallocation of resources. For example, if externalities are not reflected in prices, the resulting misaligned incentives can produce outcomes that are suboptimal from a societal perspective.

Take the example of fossil fuels: if their prices do not include the cost of $CO_2$-emissions, demand for these fuels will be higher than it would be under a proper carbon pricing regime. The resulting market equilibrium is therefore not sustainable. From this perspective, all current climate and environmental damage linked to fossil fuel use can be traced back to the failure to internalise these external costs.

The International Monetary Fund (IMF) thus refers to this lack of internalisation as a form of indirect subsidy (IMF, 2024). On the one hand, the environment suffers. On the other, these unsustainable market outcomes increase ambiguity for market participants, as it is only a matter of time before policy corrections occur – corrections that can negatively affect the profitability of investments. The most sustainable way to improve societal welfare is therefore through complete price signals.

As a second-best solution, direct subsidies are used when internalising externalities is not politically or socially feasible. These subsidy mechanisms can take many forms: tax breaks, targeted risk reduction, or direct financial support. However, direct subsidies can themselves create new externalities and unintended consequences. Policy reversals or the phasing out of subsidies are rarely straightforward and often lead to path dependencies that impose long-term societal costs.

For this reason, market interventions should only be undertaken where a specific market failure can be clearly identified. Ideally, such interventions should focus on the internalisation of externalities in order to enhance social welfare. Subsidies should only be applied when the distortion cannot be addressed through less invasive means.

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Opportunity costs are inherently embedded in market price signals. Every transaction that takes place implicitly excludes a variety of alternative transactions. This implicit allocation influences a broad set of prices across the market. Thus, when transactions occur, opportunity costs are automatically revealed through the decisions of market participants.

A practical example of this dynamic can be seen in the way industrial companies are sometimes asked whether they would be willing to adjust their electricity consumption flexibly. Understandably, many hesitate to answer affirmatively. If they signal flexibility, they may fear being pressured into delivering it - without adequate compensation. As a result, there is a strong incentive to respond cautiously or defensively.

While such surveys may yield useful insights, they rarely reflect the actual behaviour of companies under real market conditions. Market signals – particularly prices – are far more reliable in revealing the true willingness to act, since they reflect real trade-offs and revealed preferences under economic incentives.

The limited validity of survey responses stems in part from their inability to account for opportunity costs. For example, if an industrial company is operating at full capacity and curbing production would result in penalty payments due to contractual breaches, the opportunity costs of providing demand-side flexibility would be very high. In such a case, the electricity price would need to be extremely high to justify pausing production – high enough to cover potential penalties or compensate for reputational damage.

Conversely, if demand is weak and production risks exceeding storage capacity, the opportunity costs are comparatively low. In that situation, only moderate price signals would be needed to incentivise a reduction in electricity consumption. In both cases, flexible demand manifests in market bids that reflect individual opportunity costs. These bids, regardless of whether they lead to actual market-clearing transactions, still influence price formation. If high opportunity costs lead to demand being met, prices rise. If low opportunity costs lead to demand reduction, prices fall.

Ultimately, the expression of situational willingness to pay through market signals reveals information in the form of prices that cannot be obtained through any other means. This is one of the fundamental strengths of market-based coordination and a core justification for relying on price signals to guide investment and operational decisions in complex systems like the electricity market.

This example illustrates how each situation is shaped by its own contextual factors, leading to different outcomes depending on the prevailing circumstances. It also highlights that the emergence of exceptional price signals often triggers learning effects among market participants.

MARKET ACTORS LEARN HOW TO ADAPT TO NEW FRAMEWORK CONDITIONS THROUGH PRICE SIGNALS.

A notable example is October 4th, 2009, when the German electricity market experienced its first-ever negative electricity price of -500 EUR/MWh (Nicolosi, 2010). At the time, market participants were unprepared for such an event and suffered financial losses. In response, many companies began staffing their trading desks around the clock and implemented organisational changes to improve operational flexibility. These changes allowed them to better respond to similar market situations in the future. In other words, price signals also trigger organisational learning. Two seemingly identical market situations can elicit very different responses from participants depending on prior experience and internal capability.

Markets thus act not only as allocative mechanisms but also as continuous learning environments. Price signals stimulate the evolution of internal processes, investment strategies, and business models. This dynamic was evident again in 2023, when the electricity price once again dropped to -500 EUR/MWh. By then, the combination of market incentives and adjustments to the market design had significantly increased the flexibility of the electricity system – enabling ever-larger volumes of renewable energy to be integrated effectively.

The continuous upgrading of information and signalling of incentives are inherent features of a market-based system. These dynamic incentives unfold automatically through market activity and are not part of the static allocation mechanisms found in central planning or subsidy schemes. Centralised directives override incentive effects by predefining key elements of dynamic allocation – such as the required quantity, the necessary price level, or the preferred technology.

### Informational Content and Incentive Effect of the Price Signal

A prerequisite for price completeness – especially with regard to the proper internalisation of opportunity costs – is the visibility of the price signal. If consumers are unaware of the timing and level of prices at the moment of consumption, then their preferences – in terms of willingness to pay and opportunity costs – cannot be reflected in the prices. Thus, price visibility is a necessary condition for the price signal to have an incentivising effect.

Currently, most residential customers have electricity supply contracts with flat-rate pricing, where each kilowatt-hour costs the same throughout the entire contract period. Even when market prices spike due to scarcity – signalling the highest price of the year – customers have no incentive to shift their electric vehicle charging from 7:00 p.m. to 3:00 a.m., despite this shift being entirely costless in terms of comfort.

RISK IS A FEATURE OF MARKET-BASED PROCESSES, NOT A BUG.

This indifference results in unnecessarily high system costs, without offering any corresponding benefit. It is a pure externality, caused by the lack of transparency regarding the system's real-time status and electricity prices. This externality, however, can be easily internalised by providing residential customers access to market-based pricing through dynamic electricity tariffs.

The exposure to price signals – and the risk that comes with it – is not an undesirable side effect but rather a necessary feature of an effective incentive system. Prices must communicate both opportunities and risks in order to trigger behavioural responses.

Participating in a sports competition without the risk of losing would undermine the motivation to train and improve. Similarly, if consumers choose to use electricity even at high prices, this reflects a strong individual preference and transparently reveals their willingness to pay. On the other hand, if consumers face low opportunity costs – because the timing of their electricity use is not important – they can respond by reducing or shifting consumption. This too is a meaningful signal of their preference and supports an efficient allocation of resources.[17]

The technical dimension of demand-side flexibility forms the basis for the economic concept of price elasticity. By acting flexibly, consumers reveal their willingness to pay for a secure electricity supply. In this way, decentralised

[17] Neon (2023b) outlines an approach that combines effective flexibility incentives with protection against disproportionate price risks.

information is aggregated into a price signal that enables market actors to make informed decisions and support the efficient development of the electricity system.

To ensure that these incentives function efficiently, price signals must be as undistorted as possible. If artificial opportunity costs hinder market actors from responding to price signals, they create distorted incentives, which in turn distort the communication of true price elasticity.

One example of this is the current methodology for calculating network charges. According to § 17(2) of the German Electricity Grid Charges Ordinance (StromNEV), capacity-based charges are typically based on a consumer's annual peak load in kilowatts. While this approach may be appropriate in cases where power is transmitted from the high-voltage grid down to the consumer – since capacity must be dimensioned for peak loads – it can lead to counterproductive outcomes in other situations.

For instance, in a local distribution area with excess PV generation, increased consumption can actually help relieve the grid. Yet under the current regulation, a higher load results in higher network charges – even when that load supports grid stability. In such cases, the regulation effectively penalises grid-friendly behaviour. This misincentive prevents flexible consumers from revealing their true price elasticity, and in doing so, reduces the system-wide efficiency of the market.

### The High Value of Appropriate Risk

In everyday language, risk is often perceived as something negative. Yet from an economic perspective, risk simply describes deviations from the most probable outcome. For simplicity, we refer here to risks as negative deviations from the expected value, and opportunities as positive deviations.

We cannot choose the level of uncertainty we face – but we can shape how we respond to it. Since uncertainty is an inherent feature of reality, it is beneficial to design incentive structures that allow society to harness this uncertainty in a welfare-enhancing way. The financial sector, for example, has developed tools specifically aimed at managing such risks.

Options products are one such tool. They can be used to benefit from positive deviations or to hedge against negative developments. Whether it's a bet on upside potential or insurance against downside risks, different expectations, preferences, and market positions create willingness to pay. The key feature of options is their asymmetry: they come with limited losses (limited downside) but potentially unlimited gains (unlimited upside). Whether and how options are used depends primarily on their cost and the probabilities assigned to the respective outcomes.

Whether a market participant can benefit from a deviation in market expectations depends on how they have positioned themselves. Options can take a variety of forms:

- For example, a gas turbine can be understood as a real option. Similarly, partial ownership in power plants – commonly known as capacity shares – also functions as a real option. These real assets offer the opportunity to benefit from high market prices. The cost of accessing this opportunity is the fixed cost of the real option. Financial products tend to offer greater flexibility than asset-based participation.
- A flexible consumer[18] who has previously secured a hedging contract can also benefit from high prices by temporarily reducing their consumption and selling the previously purchased electricity on the spot market at higher prices. In this case, the combination of demand flexibility and procurement strategy creates a real option.
- Consumers can also use financial options to hedge against high prices. In this case, they pay a fixed premium to insure themselves against price spikes. The option seller, in turn, can use the option premium to finance the fixed costs of a gas turbine, for instance.

In this way, market risks create incentives that different market participants can use to manage their positions and preferences in the most effective way. By engaging with real-world risks, companies are encouraged to integrate these optionalities into their portfolios, thereby increasing their individual resilience while contributing to the resilience of the overall system. The need to manage real risks leads to better private decisions and creates incentive structures that enhance societal welfare.[19]

MANAGING MARKET-BASED RISKS INCREASES THE RESILIENCE OF BOTH COMPANIES AND THE SYSTEM AS A WHOLE.

In contrast, support schemes tend to shift risks onto society. In such cases, market participants have no incentive to actively manage risks, which can be considered a form of market distortion. This is because it reduces revenues for providers of hedging products and options, which in turn affects their ability to

[18] He participates in the market either directly or through his supplier.

[19] The sustainable management of private-sector risks can also incentivise technological innovation that positively affects individual risk–opportunity profiles. For example, integrating new storage technologies as a real option within the portfolio can enhance the ability to capitalise on market opportunities while simultaneously reducing exposure to adverse market developments.

offer (real) options over the long term. This market distortion diminishes the feasibility of financing peaking power plants.

Support schemes also reduce option value through clawback mechanisms. For instance, the trend toward two-sided Contracts for Difference (CfDs) lowers the option value of renewable energy generation assets. The limitation of option value through clawbacks is therefore a defining feature of such schemes. On the one hand, this can lead to higher bids in competitive renewables auctions. On the other hand, by eliminating the upside and downside of market exposure, these mechanisms reduce the very price signals that would otherwise incentivize a welfare-enhancing allocation under real-world uncertainty.

By relieving market participants from managing real-world risks, the overall system gradually loses resilience. This increasing fragility can in turn trigger further state intervention aimed at protecting businesses. The way in which market-based risks are addressed is therefore a key distinguishing feature between market-based organisational models or market designs and subsidy-based systems. To foster a strong, innovative, and resilient economy, it is thus advisable to expose market actors to both competition and real economic risks.

We have already discussed that risk plays a crucial role within the incentive system. Risk and opportunity are two sides of the same coin – together they form an efficient incentive structure. Nevertheless, market participants have a natural incentive to influence their exposure to risk through political channels. From a company's perspective, market activity is far more comfortable when it is shielded from economic risk.

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### INFOBOX: MORAL HAZARD

Moral hazard refers to a situation in which actors are more willing to take on risk because they do not bear the full cost of their actions. This can occur, for instance, when companies influence regulatory frameworks in a way that allows them to privatise profits while socialising risks. The shifting of risk from market actors to society is a structural characteristic of subsidy-based systems.

If businesses succeed in shaping policy so that society pays to reduce their entrepreneurial risk while profits remain private, this creates market distortions and results in higher costs for the public. The asymmetric distribution of risk and reward leads to misallocation of resources and a reduction in overall welfare.

A classic example of moral hazard is the bailout of companies with public funds when they face insolvency due to risky or poor decisions. Because the collapse of large firms can have negative systemic effects on the broader economy, government support is often seen as the lesser evil ("too big to fail"). If firms expect to be rescued in a crisis, they may be more willing to engage in risky business practices that promise higher profits. In such cases, risk and reward are not properly aligned, resulting in distortions that burden society.

Moral hazard can also arise when investments are supported through subsidy schemes or artificially created market segments. As companies face less downside risk due to these mechanisms, they may make more such investments than would be efficient from a market or welfare perspective. Companies are therefore strongly incentivised to promote the perceived benefits of subsidies or niche markets and to lobby for their expansion, thereby increasing their profits. Society bears the cost of these distortions – through levies, taxes, or higher prices.

When making investment decisions, companies must determine how to allocate their limited capital in the most profitable way. Financial analysis plays a key role in this selection process by identifying the most economically attractive projects. In this context, "economically attractive" means projects that promise high expected returns with relatively low associated risks. The distribution of risks therefore directly influences the market's allocation function.

If a company can reasonably assume that an investment will be economically successful, it is likely to commit large sums in order to benefit from the anticipated returns. Conversely, if an investment is considered risky, the company will tend to diversify – spreading capital across a broader portfolio to avoid being overly exposed to a single point of failure. This type of risk diversification can also lead to co-investment strategies where several partners share the risk of a single project. For example, this approach was applied in the 2000s and 2010s through so-called "Kraftwerksscheiben" (power plant shares). Companies also mitigate risk by investing in other markets with different, ideally uncorrelated, risk profiles, thereby reducing their overall exposure.

Since the Renewable Energy Sources Act (EEG) came into effect on 1 April 2000, the expansion and operation of renewable energy technologies in Germany have been financially supported to help mitigate climate change.[20] From an economic perspective, the underlying rationale is to counteract the externalities of fossil-based technologies by promoting cleaner alternatives.

[20] This description should not be understood as a criticism of renewable energy support or the expansion of renewables. It merely reflects the entrepreneurial considerations that are incentivised by regulatory frameworks and play a role in investment decisions and the design of political strategies. From the perspective of a sustainable incentive system, however, the internalisation of externalities is generally the preferable approach, as it entails fewer market distortions. Positive externalities can also be internalised and may lead to higher remuneration.

In all investment decisions, the attractiveness of a project is assessed in part based on the regulatory environment and the availability of subsidies, which directly affect the project's risk-return profile. As a result, for over 20 years, financial decision-making in corporate boardrooms has consistently favoured subsidised projects over those exposed to the full dynamics of market-based electricity segments.

Finance professionals in companies and institutions with two decades of experience have effectively been trained to prioritise investments that benefit from favourable, asymmetrical risk-return structures. It is therefore entirely understandable that companies increasingly demand public support for new investments – because the regulatory framework has conditioned them to expect it.

However, this does not imply that every investment requires public support. It merely illustrates that subsidised investments are easier for companies to undertake because they place lower demands on internal risk management. Over time, market-based, risk-exposed investments have been neglected, leading to an implicit expectation that profitable projects should come with public backing. This is a textbook example of the unintended consequences of shifting investment risks from market participants to taxpayers and consumers.

From a corporate perspective, there is a clear incentive to expand regulatory frameworks and subsidy schemes in order to benefit from asymmetric risk-return profiles. In addition, companies can often influence policy frameworks through political engagement and lobbying (rent seeking).

For a sustainable market design, however, it is essential to establish conditions that avoid triggering a subsidy competition between market segments. Such a dynamic would simply drive up total system costs without providing a commensurate societal benefit. Instead, investment incentives should be aligned with the principles of the energy policy triangle, ensuring that security of supply, environmental sustainability, and cost-efficiency are achieved at the lowest possible cost.

## 4.3 DIMENSIONS OF SECURITY OF SUPPLY

This section outlines the essential characteristics that must be met to ensure an effective and cost-efficient level of security of supply. Given the prominent role that security of supply plays in the design of electricity markets, we provide a more detailed discussion of the relevant interdependencies. In doing so, we integrate various aspects previously discussed in the context of market functioning and the role of incentives.

We have already discussed in Section 3.1 that security of supply consists of several interconnected elements. Ensuring supply security depends on the entire value chain:

- ENERGY SECURITY: the supply of primary energy, including associated logistics (e.g. natural gas and hydrogen supply or their derivatives)[21]
- GENERATION ADEQUACY: the availability of conversion technologies such as thermal power plants, hydropower, and wind and solar-based generation
- SYSTEM ADEQUACY: the transmission and distribution infrastructure, including necessary ancillary services, sensors, and control systems
- DEMAND FLEXIBILITY: the ability of consumers to react flexibly to prices increases the overall system resilience

Public and political debates around supply security typically focus on the availability of thermal power plants. While generation adequacy is a necessary condition for ensuring supply security, it is not sufficient for achieving it efficiently. The narrow focus on fuel-based or thermal generation therefore falls far short of what is needed to organise a cost-efficient and sustainable approach to supply security.

In this section, we discuss the current monitoring approaches for security of supply, highlight complementary perspectives we consider necessary, identify areas where misunderstandings often occur in public discourse, outline the role of the internal energy market, and derive implications for the organisation of supply security.

### Ensuring Security of Supply

To ensure security of supply, electricity supply and demand must always be balanced. The entire value chain contributes to the aggregate supply curve. For instance, a temporary shortage of primary energy carriers leads to a steeper supply curve, while a high share of renewable generation flattens the supply curve.

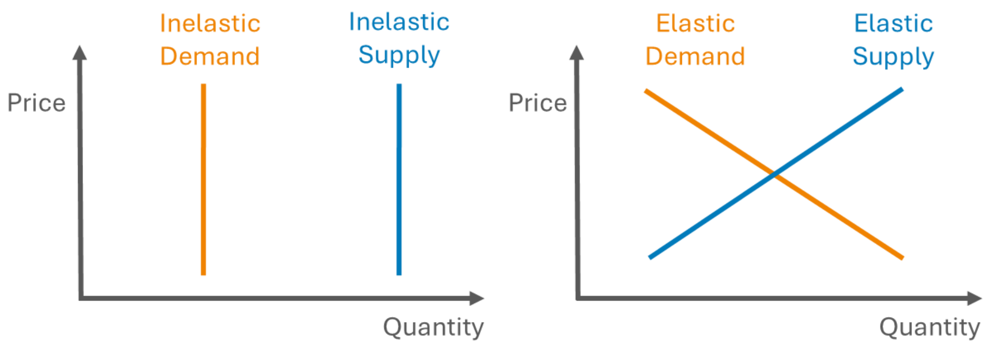
A high supply of renewables increases the elasticity of the supply curve, since the marginal cost of additional supply rises more slowly. Price-sensitive or

[21] Hydrogen is not a primary energy carrier but rather an energy storage medium. However, for the sake of simplicity, this study classifies hydrogen among the relevant primary energy sources.

flexible consumers contribute to a more elastic demand curve, as they can shift or optimise their consumption over time. If the current price exceeds a consumer's perceived utility, they may choose to forgo consumption and postpone it to a later point. This flexibility makes them an important contributor to maintaining system balance.

When both the supply and demand curves are sufficiently elastic, security of supply is effectively ensured, as a market-clearing equilibrium price can always be found. Figure 6 illustrates the relationship between elastic and inelastic supply and demand curves in a simplified way.

*Figure 6: Comparison of Elastic and Inelastic Supply and Demand Functions*




*Source: Own illustration.*

This section primarily focuses on the supply-side aspects of security of supply. The role of flexible consumers in the market-based organisation of security of supply is discussed in detail in Section 4.5.

### The Allure of Security of Supply Reports

Both German and European legislation define requirements for the preparation of security of supply reports (as per § 51 of the German Energy Industry Act [EnWG] and Articles 23 and 24 of the Electricity Market Regulation (2024) for the national and European reports, respectively). These requirements even extend to methodological details of the modelling approach, with the aim of ensuring quality and minimising arbitrary interpretations.

The methodology for assessing security of supply has advanced significantly in recent years. Until a few years ago, national capacity balances were the standard approach. This involved applying a derating factor to each generation technology, intended to approximate its contribution to security of supply at the time of peak national load. The derated capacity of all plants was aggregated and compared to historical peak demand.

This method was no longer suitable for an increasingly renewables-based system embedded in a single European market. Common points of criticism included the deterministic comparison of generation capacity and peak load, the neglect of renewable energy contributions during peak load periods, and the omission of cross-border market effects.

The new approach is based on a probabilistic analysis, which – unlike the deterministic method – allows for statements about the likelihood of a supply shortfall (using metrics such as Loss of Load Expectation [LOLE] and Expected Energy Not Supplied [EENS]). The methodology incorporates a wide range of historical weather years to model renewable energy feed-in and weather-sensitive electricity demand, as well as a broad spectrum of planned and unplanned plant outages. Furthermore, cross-border balancing effects are taken into account, significantly improving the approximation of actual market dynamics.

### INFOBOX: SECURITY OF SUPPLY INDICATORS – LOLE AND EENS

The traditional approach of capacity balances aimed to determine whether security of supply could be guaranteed even in a worst-case scenario. The probabilistic method, by contrast, evaluates a broad set of possible developments to estimate the likelihood of supply shortfalls. Two main indicators are used for this purpose:

- LOLE (LOSS OF LOAD EXPECTATION): This indicator represents the expected number of hours per year (h/a) in which electricity demand exceeds available supply on the market. The term is somewhat misleading, as an increase in LOLE does not necessarily imply involuntary demand reduction – market or system-based measures may still ensure uninterrupted supply.
- EENS (EXPECTED ENERGY NOT SERVED): This metric expresses the expected amount of unmet demand (typically measured in MWh). It is sometimes incorrectly equated with a blackout. In reality, EENS reflects that – even in the event of a shortfall – the actual volume of unserved energy is usually very limited.

Both indicators quantify the likelihood and magnitude of possible supply shortages from a market perspective. However, they do not automatically imply real-world service interruptions, as system operators have additional non-market mechanisms to maintain electricity supply for all consumers.

From a methodological perspective, expected values should not be mistaken for forecasts. The expected value represents the arithmetic mean of a wide range of possible realisations (e.g. weather years, power plant outages). A forecast, by contrast, is a specific prediction based on defined assumptions. For the calculation of expected values, scenarios may be included (such as extreme weather years) that are not realistically expected in any given year. The indicators LOLE and EENS are thus statistical reference values that incorporate extreme realisations. They are intended to guide system sizing, not to predict concrete events.

The probabilistic approach marks a significant improvement over the deterministic method. However, it places high demands on the interpretation of results. LOLE and EENS are useful indicators when the underlying data reflects real-world conditions with sufficient accuracy. This is typically the case in short-term analyses, where the near future is unlikely to differ drastically from the present.

In contrast, when the quality of information is limited – for instance, due to assumptions made about longer-term developments – there is a risk that these indicators may convey a false sense of precision. This can lead to misinterpretation and potentially flawed conclusions.

The probabilistic method translates a wide range of explicit and implicit assumptions – including model-inherent assumptions (see discussion on neoclassical theory in Section 4.1) – aggregated indicators using a mathematically precise, deterministic optimisation algorithm. If the assumptions about the future are subject to uncertainty, then the results are likewise subject to uncertainty. This trivial yet essential insight must not be overlooked when using and interpreting the results.

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These methodological advancements represent a substantial improvement in explanatory power compared to deterministic approaches. Nevertheless, the application of this method and the interpretation of its results can at times lead to misguided debates in the political arena.[22]

### The Limits of Predictability

The core issue lies in the fact that the need for comprehensive certainty about future developments cannot be satisfied. Even a detailed and mathematically

[22] A detailed discussion of the methodology and the German and European security of supply reports is beyond the scope of this study. We concentrate on the key aspects that are decisive for the market-based organisation of security of supply. The discussion is not primarily about methodological details, but above all about how the results can be used in the political debate.

sound methodology cannot resolve this fundamental epistemological problem.[23]

The expectations projected onto the security-of-supply reports arise from the combination of reporting requirements and state aid guidelines, although the latter have been somewhat softened in the most recent revision. The reports are intended to demonstrate that security of supply is ensured. If, within a foreseeable timeframe, not enough capacity is expected to be built and the statistical indicators reveal that security-of-supply criteria will not be met, capacity mechanisms may be deployed as a corrective measure. However, this should take place with sufficient lead time – the reports look up to ten years ahead – so that there is enough time to implement the capacity mechanisms and facilitate the construction of new capacities.

Reliable statements on real developments, however, cannot be made over the necessary time horizon. This is because visible scarcity in the market is required in order to trigger investment activity – unless political discussions about the introduction of capacity mechanisms inject ambiguity into the market organisation, leading to distorted political-economic incentives and resulting in investor inaction (see the discussion on misaligned and distorted incentives in Section 2.3.1). As such, the demands placed on the methodology, combined with the long lead times required, inevitably lead to a self-fulfilling prophecy at the expense of a functioning market-based organisation.

The reporting procedure therefore creates the expectation among stakeholders that complex market developments can be rendered plannable through a complicated method. But by definition, these reports cannot deliver on that expectation. As a result, the epistemological limitations of the methodology are implicitly interpreted as limitations of markets themselves. This stems from a widespread desire for certainty. Yet the true limitation lies not in the methodology, but in the ability to plan and control real-world developments. The understandable reflex to uncertainty is often a call for tighter control – also as a means of political risk mitigation. However, this impulse can motivate central interventions and rigid mandates that, by their nature, result in allocative inefficiencies.

[23] The epistemological core problem lies, among other things, in the inherent unknowability of the solution space and the unpredictability of future developments in complex systems. Decisions based on simplified models may lead to outcomes where the underlying assumptions – such as perfect foresight, the existence of market equilibrium, full rationality and complete information on the part of all decision-makers, or perfect knowledge of all available technologies – become more decisive for the results and policy recommendations than the actual conditions in the real world. The German security of supply report (BNetzA, 2023b) transparently addresses the limitations and trade-offs concerning the informative value of its findings in various sections.

### The Reduction of the Solution Space

One way to address the understandable desire for certainty lies in developing a deeper understanding of the emergent properties of market-based organisation. Understanding the effects of price signals can help build confidence that such signals will motivate market participants to invest in appropriate capacities. For example, during the energy crisis, consumption and investment patterns could be observed that were consistent with economic expectations.

However, the security of supply reports also work against this confidence. The suggestion of seemingly simple solutions to complex problems leads to a narrowing of the real-world allocation challenge to one specific outcome: the construction of new power plants. While the methodology does, in fact, take into account many interdependencies – from the role of grid infrastructure and storage to the behaviour of flexible consumers – public discussion around statistical indicators within a bidding zone rarely focuses on whether an additional transmission line or an adjusted assumption about consumer flexibility over the next ten years could address the calculated issue.[24]

Instead, the debate almost exclusively centres on power plant investments. More precisely, it is often driven by stakeholders with a vested interest in emphasising the need for capacity remuneration mechanisms. As a result, the question of how to ensure security of supply is increasingly misinterpreted as the question of how to "guarantee" power plant investments.

#### CASE STUDY: BATTERIES AS AN EXAMPLE OF UNLOCKING ADDITIONAL SOLUTION SPACES

As discussed in Section 4.1, the BMWK long-term scenarios do not project any significant build-out of battery storage systems, as – based on the explicit and implicit assumptions used in the models – batteries do not appear to be the least-cost option for meeting demand within the model framework. Nevertheless, battery storage systems are being deployed in practice for a variety of reasons, including the provision of services that are not captured in the modelling framework.

In terms of their contribution to security of supply, a study by Frontier Economics (2023) shows that battery storage systems could substitute up to 9 GW of conventional generation capacity by 2030.

If the incentive mechanisms are properly aligned with the system's objectives, it makes no difference whether these batteries are large-scale installations or

[24] Technological innovations, however, are inherently overlooked due to methodological constraints. These forms of ignorance cannot be captured within the modelling framework – yet they are crucial for real-world developments.

aggregated into virtual power plants composed of many decentralised storage units and other flexibility options.

The security of supply reports are characterised by a high degree of methodological quality. For short-term assessments – one or two years ahead – they provide meaningful and actionable insights. However, over a time horizon of up to ten years, the quality of available information declines significantly, which limits the reliability of the resulting indicators. While this methodological approach is appropriate for network infrastructure planning due to the regulatory requirements involved, it is not suitable for market-based processes.

The approach taken by the security of supply reports to address real-world uncertainty is reminiscent of the parable of the drunkard searching for his keys under a streetlamp. When asked by a passerby whether he lost them there, the man replies: “No, I lost them over there – but the light is better here.” Just because the methodology provides the best available tool to calculate something does not necessarily mean that the resulting indicators are suited to answering the underlying question.

The challenge therefore lies in how these reports are used in the energy policy debate. By suggesting that complex systems are predictable and controllable, they create an expectation of control. Instead, the focus should be on further developing incentive-compatible market-based framework conditions to ensure security of supply cost-efficiently, using all available means.

THE FOCUS SHOULD BE ON FURTHER DEVELOPING INCENTIVE-ALIGNED FRAMEWORK CONDITIONS TO ENSURE SECURITY OF SUPPLY COST-EFFICIENTLY, USING ALL AVAILABLE MEANS.

### Primary Energy Availability

No primary energy source is available at all times or entirely secure.[25] Moreover, the use of each energy carrier involves specific requirements along the value chain that affect its reliable availability. The uncertainties associated with pipeline-based gas supply became evident during the Russian war of aggression against Ukraine. Hydropower plants depend on sufficient inflow and precipitation to generate electricity. Low water levels in inland waterways can also impact the cooling and thus the availability of nuclear power plants.

[25] This applies in principle to all technologies. A strong concentration on individual technologies can also give rise to systemic risks. In Germany, the use of T-25 steel in coal-fired power plants led to problems across an entire generation of plants. During the energy crisis, the French nuclear fleet experienced significant unavailability due to maintenance work at numerous reactors and low water levels, which restricted cooling capacity.

Similarly, low water levels can restrict coal transportation. We also experience daily that the sun does not always shine and the wind does not always blow. No single primary energy source can therefore fully ensure a secure supply on its own.

In the future, we will probably rely on the availability of hydrogen to fuel thermal power plants in order to meet electricity demand that cannot be covered by renewable energy sources. However, significant uncertainties currently remain regarding both the availability and cost of this back-up option.

However, we can assume that trading liquidity is likely to be limited, particularly It can be assumed that during the early stages of market development, trading liquidity will be limited. This will create additional uncertainty regarding both hydrogen availability and price levels. For example, in 2023, employees at an Australian LNG terminal threatened to strike, leading to a surge in European gas prices by up to 40 percent (Bloomberg, 2023). It will take many years before the global hydrogen market reaches a level of liquidity comparable to that of the LNG market. Therefore, price volatility for hydrogen is expected to be considerably higher than for LNG.

TECHNOLOGICAL CONCENTRATION AND THE RESULTING DEPENDENCE ON SPECIFIC ENERGY CARRIERS CAN UNDERMINE SECURITY OF SUPPLY.

Hydrogen also has a lower energy density than methane.[26] As a result, even if the current natural gas storage infrastructure were entirely converted into hydrogen storage, the total amount of storable energy would be significantly reduced. However, this limitation is somewhat offset by the fact that overall hydrogen demand is expected to be lower than historical natural gas consumption. This means that the impact of reduced storage capacity would be mitigated to a certain extent.

Since the entire value chain is crucial for ensuring security of supply, it is not only the availability of power plants that matters, but also the sufficient availability of hydrogen. Given the anticipated scarcity of hydrogen during the market ramp-up phase and the likely high prices, every cost-efficient alternative option for meeting electricity demand strengthens security of supply by reducing fuel consumption. These savings would also lower overall system costs, as hydrogen-fired gas turbines are expected to be the most expensive form of electricity generation for the foreseeable future. Every kilowatt hour of hydrogen saved therefore improves security of supply and reduces system costs.

[26] The calorific value of hydrogen is approximately 3.0 kWh/m³, while that of methane is around 9.97 kWh/m³ (Energie Lexikon, 2024).

For this reason, the market design should incentivise the use of alternative options for meeting electricity demand by establishing competitive framework conditions. In addition to the batteries discussed in the previous section, the internal electricity market – covered in the following section – and flexible consumers – discussed in Section 4.5 play crucial roles.

### The Value of the Internal Market for Cost-Efficient Security of Supply

In 1951, the UCPTE (Union pour la coordination de la production et du transport de l'électricité) was established with the aim of coordinating the synchronous operation and development of the electricity transmission network in continental Europe to ensure a reliable power supply across the interconnected system. The benefits of cross-border cooperation for both security of supply and cost efficiency were therefore recognised and accepted early on.

Nonetheless, there are voices critical of electricity imports. This is surprising, given that Germany has long imported a significant share of raw materials, intermediate goods, and primary energy sources. When it comes to electricity supply, primary control reserve is certainly the most critical element due to its strict temporal requirements. Since the publication of the UCTE (Union for the Co-ordination of Transmission of Electricity) Operation Handbook in 2004, primary control reserve has been dimensioned across borders. Thus, the secure supply of electricity has been a shared European responsibility at least since 2004.

Sometimes it is criticised that Germany imports electricity from nuclear power, even though it has opted not to produce it domestically. However, such criticism contradicts both the European idea and economic principles. EU Member States retain sovereignty over their energy mix. Any alternative approach would risk undermining cohesion within the EU. Ultimately, it is this combination of shared principles and national differences that defines Europe.

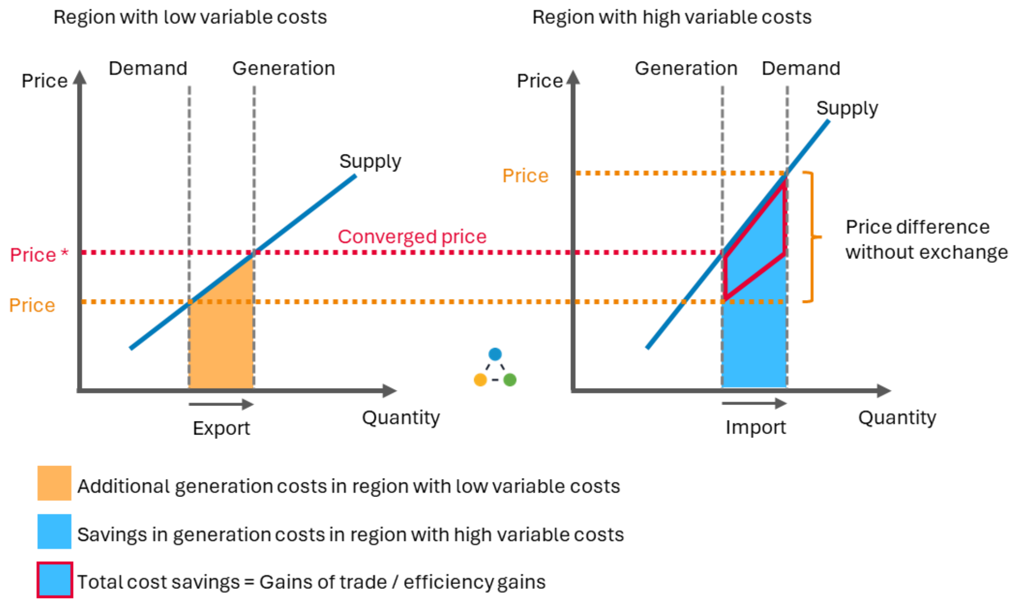
TECHNOLOGICAL DIVERSIFICATION IN THE INTERNAL MARKET ENHANCES THE EFFICIENCY AND SECURITY OF ELECTRICITS SUPPLY.

The dependency on Russian gas imports led to high costs for businesses and households during the energy crisis. This experience should serve as a valuable lesson. However, the rational conclusion is diversification, not autarky. Autarky would be an overreaction – one that would result in substantial welfare losses. Instead, cooperation within a community of shared values should be strengthened to increase resilience and societal welfare.

Deepening European cooperation and integration is the most effective response to today's growing geopolitical risks. The added value of intra-European diversity is also evident in the diversification of the European power mix.

It is precisely the diversity of energy sources and technologies that enables mutual benefits – both economically and in terms of security of supply. The differences between regions are therefore not a disadvantage, but a strength that should be leveraged as effectively as possible. Figure 7 illustrates the cost savings resulting from electricity exchange between two bidding zones.

*Figure 7: Cost Savings Through Cross-Border Electricity Exchange*




*Source: Own illustration.*

In Figure 7, the benefits of cross-border electricity exchange are illustrated from two angles:

- On the one hand, electricity trade lowers fuel costs and price volatility.
- On the other hand, generation capacity is used more efficiently, enhancing security of supply and reducing long-term fixed costs.

These reductions in total system costs highlight the welfare gains of the internal electricity market. According to ACER (2022), the financial value of the EU internal electricity market was estimated at €34 billion per year. With a growing share of renewable energy and increasing price volatility, this value is expected to rise further in the coming years.

In the next section, we will explore how the internal market not only reduces variable costs but also contributes to lowering fixed costs in the electricity system. This further underscores the positive effect of the internal market on security of supply from a welfare perspective.

## 4.4 THE CHALLENGES OF A DYNAMIC RENEWABLE-BASED POWER SYSTEM

In a static system, where key elements remain largely unchanged over time, the availability and quality of information about the foreseeable future is relatively high: peak demand can be estimated with reasonable accuracy, and the technologies needed to meet that demand are fairly well understood. This makes static systems comparatively easy to plan.

In contrast, dynamic renewable-based systems operate under significantly greater uncertainty – especially when innovation and emerging technologies are factored in. It is much less clear how much of which technology will ultimately be needed. As a result, a different kind of discovery process is required – one that can aggregate the widely dispersed, decentralized information and enable decision-making based on that evolving knowledge.

### The Transformation Process of the Capacity Mix

Economic analyses often focus on market equilibria. However, the true quality of a sustainable market design becomes evident when it is also capable of organising dynamic transformation processes. Understanding these processes requires close attention to the interaction between short-term price signals and long-term investment and disinvestment decisions. Figure 8 illustrates the supply and demand functions of the spot market.

*Figure 8: Illustrative Representation of Spot Market Supply and Demand Functions*


*Source: Own illustration.*

In Figure 8, it becomes evident that both the supply and demand curves feature elastic and inelastic segments. In the flatter, more elastic sections, a small change in price leads to significant adjustments in volume. In contrast, in the steeper, more inelastic areas, volumes respond less to price changes. With a growing share of renewable energy and the increasing deployment of decentralised flexibility options, these curves tend to become more elastic over time – provided the market design is incentive-based.

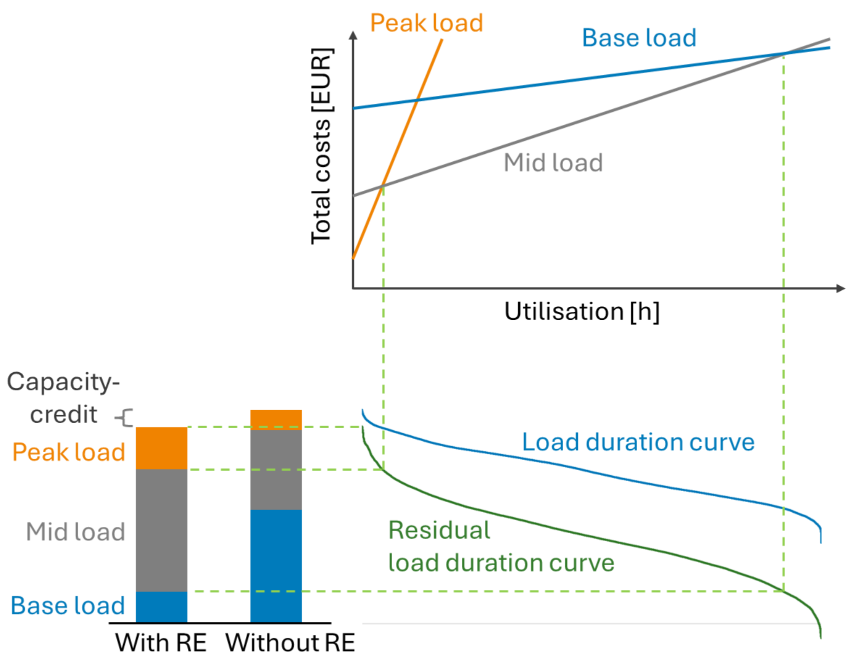
HIGH PRICE ELASTICITY OF DEMAND ENHANCES SECURITY OF SUPPLY.

Greater elasticity enhances security of supply by increasing the likelihood of market clearing. In the remainder of this chapter, we will explore how the elasticity of different segments of the supply and demand curves evolves over time and what implications this has for the organisation of a reliable electricity system.

The requirements for the supply structure are determined by the residual demand, i.e. electricity demand minus variable renewable generation. In the lower right quadrant of Figure 8, the load duration curve is contrasted with the residual load duration curve. The upper right quadrant illustrates simplified cost structures of available technology options. Peaking technologies are characterised by low investment costs and relatively high generation costs. Baseload technologies have high fixed costs and relatively low variable costs.

The economic characteristics of different technologies, combined with the load structure, enable a cost-optimal generation mix. As the (residual) load profile – served by dispatchable technologies – changes, the optimal technology mix also shifts. Figure 9 illustrates how increasing penetration of renewable energy leads to a steeper residual load curve, which in turn changes the optimal composition of the dispatchable generation mix.

*Figure 9: Change in the Generation Capacity Mix Due to the Expansion of Renewable Energy*




*Source: Own illustration.*

In Figure 9, it becomes apparent that the changing structure of residual demand – caused by a higher share of renewable energy – leads to a shift in the optimal composition of the generation fleet. The efficient share of baseload capacity decreases significantly, while the shares of mid- and peak-load technologies increase. Accordingly, a cost-optimal technology mix continuously adjusts to the growing share of renewables, with an increasing reliance on mid- and peak-load technologies to meet the declining residual demand.

The role of peak-load technologies can be fulfilled by various technologies that are characterised by low investment costs and higher variable costs. Public debate typically focuses on gas turbines. However, gas turbines require a relatively high number of full-load hours to be financially viable in the electricity market.[27] For technologies with fewer operating hours, other peak-load solutions may be more cost-efficient – either because they involve lower capital expenditure, or because their fixed costs do not need to be recovered through the electricity market, as their primary purpose lies elsewhere.

[27] In addition to their role in the electricity market, gas turbines can also serve other functions. For instance, they can be used to hedge balancing groups in the sense of a real option, which can likewise contribute to their refinancing.

Peak-load technologies also include what are often referred to as unconventional flexibility options. For example, backup power units are installed to secure critical infrastructure in the event of grid failures. The investment in such units does not need to be refinanced through the electricity market, but they can still generate a positive value as peak-load technologies without compromising their primary purpose. A similar effect can be provided by technologies such as bidirectional electric vehicles or other flexible assets. Electric vehicles primarily serve a mobility need. However, considering individual mobility preferences and willingness to pay, they can also deliver value to the electricity system when integrated into virtual power plants. Unconventional peak-load technologies are characterised by the fact that they do not require cost recovery via electricity market revenues, as they meet other primary needs. Nevertheless, they can have a positive effect on security of supply when incentivised to behave flexibly through price signals.

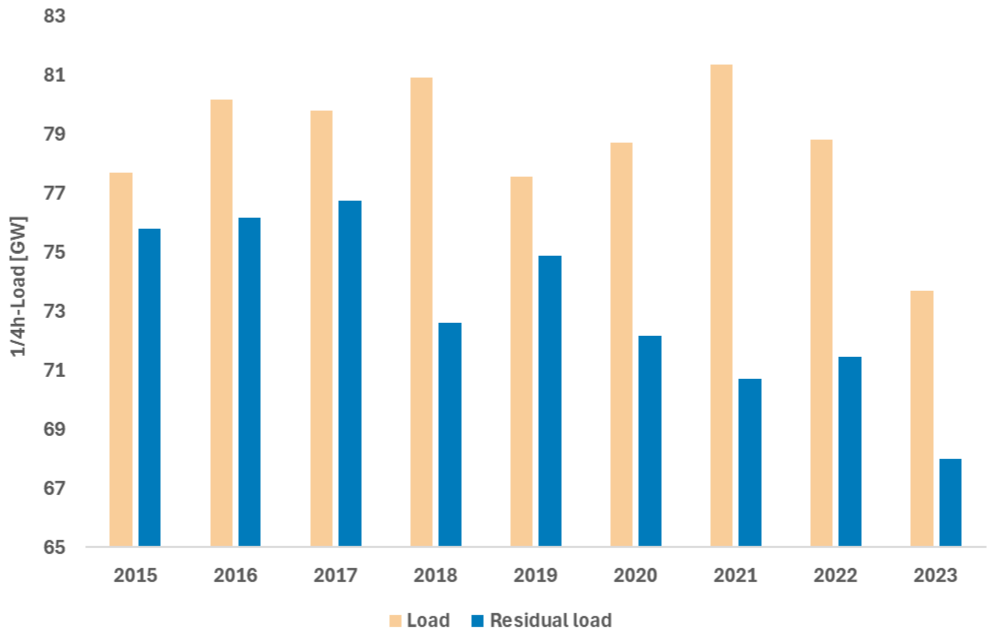
INCREASINGLY, THE ECONOMICALLY EFFICIENT RESPONSE IS NOT TO BUILD NEW GAS-FIRED POWER PLANTS, BUT TO UTILISE FLEXIBILITY OPTIONS.

Figure 9 also illustrates that the total installed capacity decreases due to the so-called capacity credit of renewable energies. The capacity credit reflects the probability that a small share of renewable generation is available to contribute to peak load coverage during periods of high demand.[28]

To illustrate this effect, Figure 10 contrasts peak load with residual peak load over recent years. This representation is intended for illustrative purposes only. In contrast, the calculation of the capacity credit is based on the use of a probabilistic methodology.

[28] See Connect (2021) for a detailed explanation and discussion of the capacity credit.

*Figure 10: Comparison of Peak Load and Residual Peak Load from 2015 to 2023*

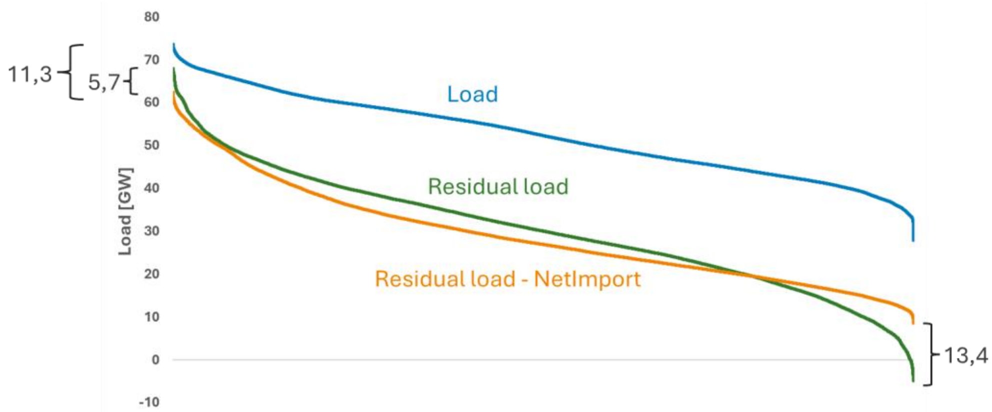



*Source: Own illustration, data from entsoe (2024), own assumptions.*

Based on Figure 10, it becomes apparent that residual peak load in recent years has often been significantly lower than the highest absolute load. During the observed period, the highest overall load was approximately 81.4 GW, while the highest residual load reached around 76.8 GW. While these figures do not directly indicate the capacity credit, the following general principle applies: the higher the correlation between renewable generation and peak load, the greater the capacity credit and the lower the amount of controllable generation capacity required to ensure security of supply.

Increasing integration into the European internal electricity market has a similar effect due to the smoothing of renewable generation profiles and demand structures across borders. If, during a peak load situation, electricity generation in Germany is more expensive than importing electricity, the demand can be met more cost-efficient through imports. As a result, the internal market can reduce both generation costs and, to some extent, fixed costs. Figure 11 illustrates this by comparing the load duration curve, the residual load duration curve, and the residual load duration curve adjusted for net imports. This adjusted residual load duration curve can be interpreted as the level of demand that the German electricity system must address domestically.

*Figure 11: Comparison of the Load Duration Curve, the Residual Load Duration Curve and the Residual Load Duration Curve Adjusted for Net Imports for 2023*

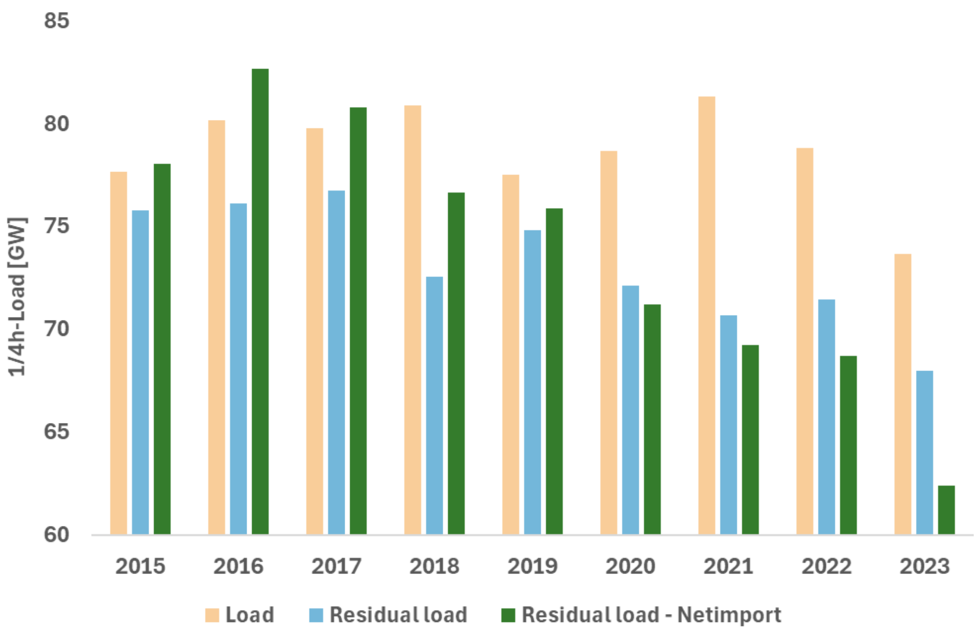



*Source: Own illustration, data from entsoe (2024), own assumptions.*

Figure 11 illustrates that, in 2023, the peak load that had to be addressed by the German power system decreased due to the availability of imports. Compared to the residual peak load, 5.7 GW less dispatchable generation capacity was needed, and compared to the absolute peak load, the reduction amounted to 11.3 GW. Export opportunities further enabled the integration of larger volumes of renewable electricity, as reflected in the 13.4 GW increase in the lowest corrected residual demand.

By blending renewable generation, differing national demand profiles, and diverse technology mixes (portfolio effect), the internal electricity market enhances security of supply. As a result, the required firm capacity decreases across all Member States. Figure 12 presents the peak load, the residual peak load, and the net-import-adjusted residual peak load to illustrate the amount of demand that must be addressed by the German electricity system.

*Figure 12: Comparison of Peak Loads, Residual Peak Loads and Residual Peak Loads Adjusted for Net Imports from 2015 to 2023*



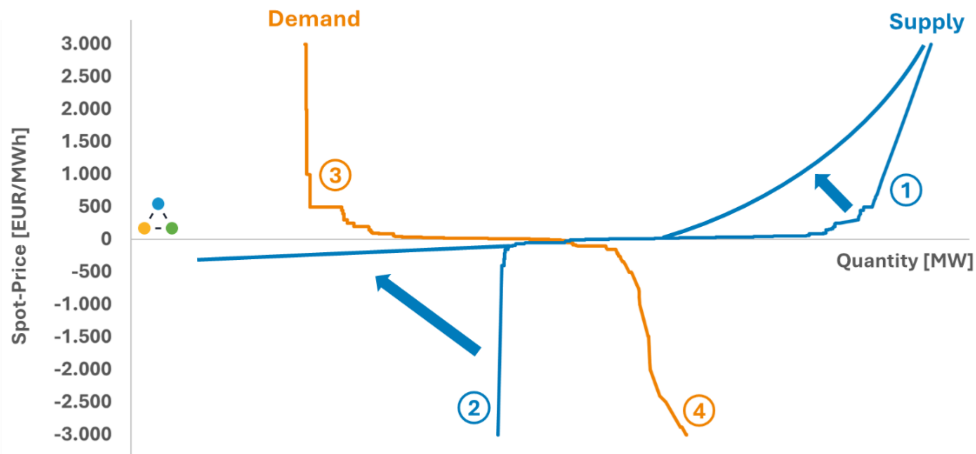

*Source: Own illustration, Data from entsoe (2024), own assumptions.*

Figure 12 shows that the net-import-adjusted residual peak load can lie either above or below the (residual) demand peak. If the adjusted residual peak load exceeds the residual demand peak, this indicates high export volumes, overcapacity, and a suboptimal generation mix. Given the benefits of cross-border diversification, all Member States should be able to leverage the internal market to reduce their firm capacity needs. Consequently, the trend observed in recent years points to a more efficient generation mix that reduces system costs by taking advantage of capacity credit mechanisms and the internal market.

These system-wide efficiency gains translate into lower total costs for EU citizens, thereby enhancing overall social welfare. However, for conventional generators, these gains materialise as reduced full-load hours and diminished revenues. From their perspective, declining profitability of existing plants provides a rationale to advocate for capacity payments. Nevertheless, the combined impact of capacity credits, the internal market, and the integration of flexible and innovative technologies can significantly reduce total system costs.

The adjustment of the supply curve (1) to the rising share of renewables and the integration of the internal market is illustrated in Figure 13.

*Figure 13: Illustrative Representation of Supply Adjustment to Renewables and the Internal Market.*




*Source: Own illustration.*

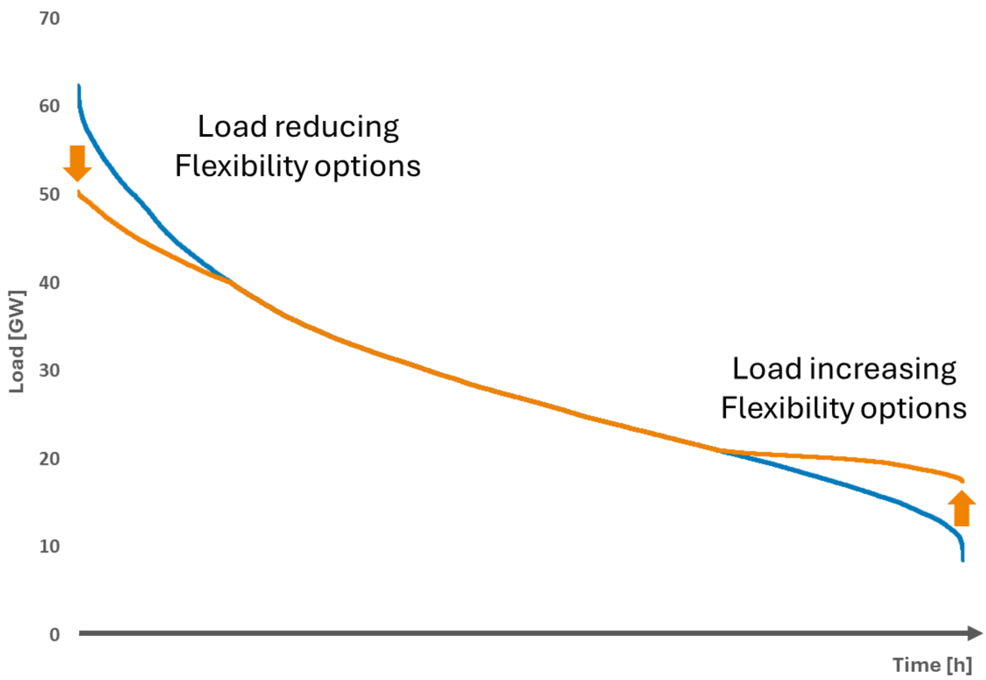
As the share of baseload technologies declines and the share of peaking technologies increases, the supply curve shifts upwards, resulting in a correction of the overall price level.

Segment (2) is not the primary focus of this study. However, flexibility in this segment is increasingly feasible, particularly as renewable generators are incentivised to adopt flexibility options that allow them to market electricity during higher-price periods. For instance, recent trends show that PV parks are either directly integrating battery storage or reserving space to retrofit storage solutions in the future. This flexibilisation of the supply curve helps dampen price volatility, thereby supporting the market value of renewable electricity.

A SUSTAINABLE MARKET DESIGN IS CAPABLE OF INCENTIVISING A WIDE RANGE OF INNOVATIVE FLEXIBILITY OPTIONS IN ORDER TO REDUCE OVERALL SYSTEM COSTS.

The use of flexibility options enables renewable energy sources to provide greater value by shifting supply or demand over time. At the same time, these options help to reduce peak load situations compared to the previous illustrations. Figure 14 provides an illustrative overview of how flexibility can lead to a shift in the demand curve.

*Figure 14: Illustrative Representation of the Effects of Flexibility Options*




*Source: Own illustration, data from entsoe (2024), own assumptions.*

Flexibility options can be implemented on both the supply and demand side. Figure 14 illustrates – using the residual load duration curve – how these options can reduce peak demand while improving the integration of renewable energy sources. By increasing the market value of renewables, flexibility options reduce the need for subsidies and thus contribute to greater societal welfare.

A sustainable market design should therefore be capable of incentivising a broad range of flexibility options in order to unlock their diverse potential for reducing total system costs.

### The Greatest Challenge to Security of Supply from Today's Perspective

The availability of primary energy from wind and solar sources is insufficient during cold dark doldrums (periods of low sun and wind), making it impossible to fully meet demand. The advantage, however, is that this situation is well known and can be calculated on the basis of historical statistical data. For example, if an analysis shows that a power plant is used every three years for a few hours to cover such an event, it is highly likely that market participants will find a more cost-efficient way to meet this demand – provided that the incentive system is appropriately designed. In other words, a dark doldrum represents a risk that can be managed.

In contrast, the sudden loss of Russian gas supplies was a case of ambiguity – an event that, while theoretically conceivable, could not be reliably calculated. As such, this scenario could not be addressed in advance by market-based incentives. The type of uncertainty therefore determines the type of organisation needed to deal with it (see the discussion of uncertainty categories in Section 2.3.2).

At this point in time, it remains unclear how the hydrogen market will develop. A broad import portfolio would reduce the risk of supply disruptions. Nevertheless, due to ongoing geopolitical developments, the procurement outlook remains ambiguous and cannot currently be reliably assessed.

Basing future security of supply solely on this ambiguous scenario could therefore constitute a premature commitment – one whose level of certainty cannot be reliably calculated. In contrast to such a predetermined approach, market-based incentives can be used to organise the allocation of technological solutions to ensure security of supply. Hydrogen can indeed play an important role within this portfolio of solutions. However, a market-based allocation also enables the use of complementary options that can contribute to a reduction in overall system costs.

In every specific situation, there is a range of substitutes for hydrogen-based power generation (e.g. demand-side flexibility, imports, etc.). When these substitutes are available at a given point in time, they displace hydrogen-based generation due to cost advantages. Allowing price signals to incentivise such cost-efficient alternatives to secure electricity supply is beneficial both for system adequacy and for reducing overall system costs.

COMPETITION IN THE ELECTRICITY MARKET INCENTIVISES TECHNOLOGICAL DIVERSIFICATION, THEREBY ENHANCING SECURITY OF SUPPLY.

If market participants identify a calculable need combined with a sufficient willingness to pay, a suitable offer will emerge to meet that demand. Market actors are typically in a better position to assess which technologies can meet this demand than political decision-makers, due to information asymmetries. If the market-based system remains open to innovation, the resulting solution is likely to be both more secure and more cost-efficiently than one imposed by central planning.

The role of a sustainable market design is therefore to address foreseeable challenges as cost-efficiently as possible by leveraging all available solution options. As discussed in this section, the internal market can already be part of the solution. In the next section, we will explore the various roles that flexible consumers can play in addressing these challenges – provided that the appropriate regulatory framework is in place.

## 4.5 THE SPECIAL ROLE OF FLEXIBLE CONSUMERS

In this section, we build on the previous chapters to explore the role that flexible consumers can play in organising supply security. The limited flexibility of electricity consumption has long been one of the most relevant market imperfections in the electricity sector. When consumption data for large parts of the customer base is collected manually once a year, important information and incentives are missing for the market system to function properly.

- The timing of consumption is not visible
- The electricity price is not transparent to consumers
- Individual preferences and willingness to pay are not apparent
- Consumers cannot be excluded from electricity consumption

Due to this lack of information and incentives for large groups of consumers, more extensive regulatory measures have traditionally been necessary (see e.g. Cramton et al., 2013). A well-functioning market is characterised by price-elastic consumption behaviour that makes individual preferences visible through willingness to pay. In this way, preferences are reflected in electricity prices, enabling the system to send effective signals.

### The Importance of Individual Willingness to Pay

Taking individual willingness to pay into account is a fundamental principle of economic organisation. It expresses the value that a consumer places on using a specific product at a specific point in time.

If consumption occurs despite incomplete information about the current electricity price – and the individual utility derived from that consumption is lower than the current price – then external costs arise. For example, an electric vehicle might be charged at 7:00 p.m., contributing to a very high market price that could signal the need to build a new power plant. If the consumer were asked whether it is important to charge at 7:00 p.m., or whether charging at 3:00 a.m. would be acceptable, then system costs could be reduced if the consumer is flexible. The price signals at 7:00 p.m. and 3:00 a.m. essentially ask that question.

It is sometimes wrongly assumed that flexible consumer behaviour is inherently good and inflexible behaviour inherently bad. This perspective stems from a purely technical system logic. From an economic point of view, the actual behaviour is of secondary importance. What matters is whether that behaviour is based on complete information about the consequences of consumption – as aggregated and conveyed through the electricity price.

IF THE UTILITY OF ELECTRICITY CONSUMPTION IS HIGH, FLEXIBLE CONSUMERS SIGNAL THEIR WILLINGNESS TO PAY BY CONSUMING DURING HIGH-PRICE PERIODS.

If the utility of consumption is high – as expressed through a high willingness to pay – then consuming electricity even during high-price periods is consistent and economically rational behaviour. The high utility is reflected in the willingness to pay, which in turn sends a market signal that can help market participants identify a genuine demand for additional generation capacity. As long as the behaviour is consistent with the perceived utility (i.e. reflected in the willingness to pay), the price signal conveys accurate and welfare-enhancing information.

However, if consumption takes place without knowledge of the system state – because the price of electricity is not visible or has no incentive effect for the consumer – then individual preferences are not properly communicated. In this case, the result is a market distortion that leads to external costs.

These external costs can be internalised by enabling consumers to express their utility through their willingness to pay – by giving them access to price signals and the incentive to consider these signals in their consumption decisions. In the UK, Bobbio et al. (2022) compared the consumption behaviour of residential customers on fixed tariffs with that of customers using dynamic tariffs. They found that for customers with dynamic tariffs, a one-percent price increase led to an average reduction in demand of 0.265%. Price elasticity was higher among customers using technologies such as electric vehicles and heat pumps.[29] According to the authors, this level of price elasticity is sufficient to maintain security of supply in extreme situations.

For Germany, Hirth et al. (2024) analysed the overall price elasticity of electricity demand. They found that a price increase of €1/MWh led to a load reduction of 67–80 MW. This corresponds to a price elasticity of approximately 0.05, which

[29] Bobbio et al. (2022) also point out that low-income households benefit the most from dynamic electricity tariffs.

the authors mainly attribute to industrial consumers, as there were very few households with smart meters in Germany during the observation period.

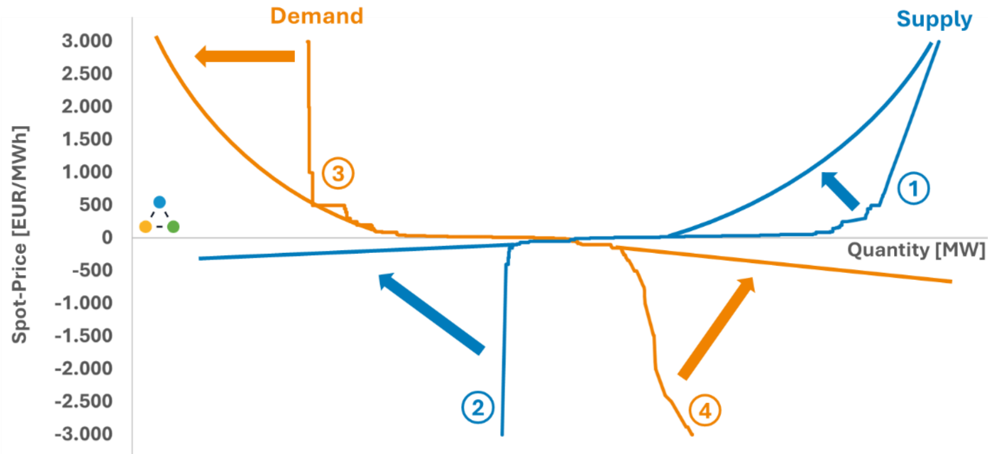
For both studies, it is important to note that the specific figures only apply to the periods under investigation. As incentives change, behaviour may also change. Moreover, consumers tend to learn and adapt their behaviour, particularly during periods of high prices – and this learned behaviour can benefit them in other market phases as well.

EMPIRICAL ANALYSES SHOW THAT INDUSTRIAL CONSUMERS AND HOUSEHOLDS RESPOND FLEXIBLY TO PRICE SIGNALS, THEREBY ENHANCING SECURITY OF SUPPLY.

It is therefore a robust empirical observation that industrial consumers and households respond to price signals and adjust their behaviour in line with the incentives. In doing so, they increase the likelihood that supply and demand curves intersect in the electricity market, which in turn enhances security of supply.

At the same time, the intersection of supply and demand implies that a price is signalled which reflects consumers' willingness to pay, including their opportunity costs. Figure 15 illustrates the effects of increasing demand elasticity in the spot market.

*Figure 15: Illustrative Representation of the Expansion of Demand Elasticity*




*Source: Own illustration.*

Figure 15 illustrates how increasing demand elasticity (3) manifests itself in the market at high prices. Flexible consumers reduce their demand when prices rise, thereby signalling their willingness to pay. As a result, the price signal increases less abruptly and, in turn, provides investors with information about whether an expansion of supply would meet a demand that is actually willing to pay for it.

Section (4) also shows that flexible consumers can increase their consumption in times of high supply and correspondingly low prices. It is sometimes mistakenly assumed that signalling high prices to consumers necessarily leads to high costs for them. However, this is incorrect. The total system costs must be covered one way or another. Depending on the chosen method of cost allocation, it is simply a question of whether those costs are borne by consumers or taxpayers.

BY INTERNALISING ALL COST COMPONENTS INTO THE PRICE SIGNAL, FLEXIBLE CONSUMERS CAN REDUCE BOTH THEIR INDIVIDUAL COSTS AND OVERALL SYSTEM COSTS.

Through the price signal, consumers are given the option to influence both the amount and timing of their electricity use in order to manage their individual costs. Without this signal and its associated incentive effects, consumers have only limited ability to influence their own costs and, by extension, overall system costs. If system costs are instead financed through levies or taxes, efficiency-enhancing incentives are removed, leading – due to the externalities discussed above – to higher total system costs. Internalising all cost components into the price signal ensures that consumers receive appropriate incentives to align their consumption with their individual utility, thereby contributing to a more cost-efficient overall system.

### The Relevant Market Imperfection Is Gradually Being Resolved

As outlined at the beginning of this chapter, the key market imperfection that has historically justified state intervention in the organisation of security of supply was the limited role of flexible consumers. Due to the analogue infrastructure, consumers previously lacked both the necessary information and the relevant incentives to align their consumption behaviour with system needs.

The economic good classification scheme provides a framework for determining how goods are treated in the market based on their fundamental characteristics. The two key dimensions are rivalry in consumption and excludability. If neither applies, the good is classified as a public good. For small consumers, electricity was historically a common good (or common-pool resource) because, although there is rivalry in consumption during peak load situations, there was no technical means of excluding consumption due to the lack of smart metering infrastructure. In contrast, for large consumers, electricity has always been a private good, as load metering ensures both rivalry and excludability. Figure 16 illustrates this economic good classification scheme.

*Figure 16: The Economic Goods Classification Scheme*

| | | Rivalry: No | Rivalry: Yes |
|---|---|---|---|
| Excludability | No | **Public good** | **Common-Pool-Resource** |
| | Yes | **Club good** | **Private good** |

*Source: Own illustration.*

As the smart meter infrastructure expands, electricity will increasingly shift from being a common-pool resource to a private good. This transformation will enable the market-based organisation of security of supply based on individual preferences.

> BECAUSE OF PRICE-ELASTIC DEMAND, ELECTRICITY SUPPLY CAN BE ORGANISED THROUGH MARKET MECHANISMS.

It is sometimes argued that electricity should be considered a merit good. Merit goods are defined as goods that public institutions believe should be consumed more than individual willingness to pay would suggest. This public interest is understandable in the case of education and healthcare, as both are associated with positive externalities. For example, higher levels of education generate positive economic externalities through increased value creation and job opportunities. Similarly, good public health leads to positive value creation and reduces pressure on the healthcare system.

It is, however, not apparent why higher individual electricity consumption should result in a positive societal effect. On the contrary, electricity consumption typically entails negative externalities – either in the form of direct environmental impacts or the increased need for resources to ensure sufficient generation capacity.

On the other hand, there are strong arguments in favour of a societal benefit resulting from a guaranteed minimum level of electricity supply. A lack of access to electricity would impair the satisfaction of basic needs. For example, electric lighting improves opportunities for education, and the refrigeration of food supports healthy nutrition. Ensuring a minimum level of supply is therefore desirable to capture the positive externalities of meeting basic needs.

From this perspective, the basic supply of electricity exhibits the characteristics of a merit good, while electricity consumption beyond this minimum level resembles the characteristics of a private good. Translated into market terms, this would imply that the demand curve consists of both an elastic and an inelastic segment. In Chapter 6.2, we will discuss how this differentiated classification within the economic goods framework can be reflected in the market-based organisation of security of supply.

### Market Equilibrium in a Dynamic and Complex Power System

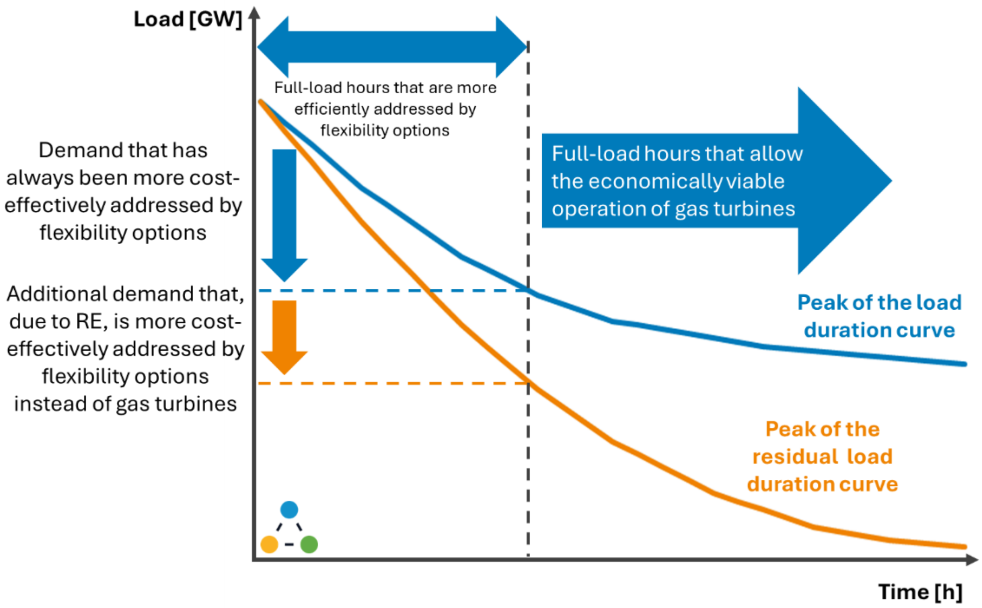
The growing share of decentralised consumption and storage technologies – especially electric vehicles, heat pumps, and home batteries – increases the complexity of the electricity system and, in turn, the coordination challenge for efficient resource allocation. In the absence of dynamic electricity prices, these technologies naturally tend to operate simultaneously:

- Electric cars are typically charged after work.
- Heat pumps consume electricity when it is cold.
- Home storage systems charge as soon as PV generation exceeds on-site demand in the late morning. The use of the stored electricity is generally aimed at reducing the aggregated grid electricity consumption, rather than responding to the state of the electricity system, as signalled by wholesale market prices. As a result, the use of home batteries does not necessarily align with system or market conditions and therefore does not automatically contribute to a reduction in peak load.

To prevent these technologies from creating disproportionately high peak loads that could overwhelm the power system, their aggregated operation must be orchestrated through the price signal. Behind each decentralised unit lie individual consumption preferences and willingness to pay, giving rise to a level of complexity that can only be managed through market-based coordination.

A key question this market coordination must answer is: How much flexibility is available, and how much controllable capacity is needed? This allocation challenge cannot be addressed reliably and cost-efficiently through central planning. Only a decentralised market organisation, based on individual willingness to pay, can account for the complex interactions in the system. Moreover, the share of capacity that can be provided more cost-efficiently by flexibility options increases with the growing penetration of renewables. Figure 17 illustrates the shift in equilibrium using load duration curves (abstracting from the capacity credit of renewable energies).

*Figure 17: Illustrative Representation of the Efficient Allocation Between Flexibility Options and Gas Turbines*




*Source: Own illustration.*

As the peak of the residual load duration curve becomes increasingly steep due to the growing share of variable renewable energy, the average utilisation of peak-load technologies declines. Conventional generation technologies are not the most cost-efficient technological option to cover rarely occurring peak loads. To ensure a cost-efficient overall system, peak-load situations are better addressed by technologies with lower fixed costs and higher variable costs. These are typically unconventional flexibility options and price-responsive consumers who make use of various flexible technologies.

THE PRIMARY VALUE OF PRICE-RESPONSIVE CONSUMERS LIES NOT ONLY IN THEIR FLEXIBLE CONSUMPTION BEHAVIOUR, BUT ALSO IN SIGNALING THEIR WILLINGNESS TO PAY, WHICH PROVIDES A RELIABLE INVESTMENT SIGNAL FOR INVESTORS.

By expressing their willingness to pay through consumption behaviour that reflects complete price signals, consumers also provide investors with critical information about the required level of generation capacity. The primary value of price-responsive consumers therefore lies not only in their flexible consumption, but above all in their ability to signal their fundamental willingness to pay – offering a reliable investment signal to the market.

This market-based discovery process enables an efficient allocation between millions of flexible consumption and storage technologies – each with individual usage preferences – on the one hand, and thermal generation technologies on the other. The goal of policymakers should therefore not be to determine the answers to these complex allocation challenges themselves, but rather to create the conditions under which market actors can provide cost-efficient solutions.

THE GOAL OF POLICYMAKERS SHOULD NOT BE TO PREEMPT THE ALLOCATION TASK, BUT TO CREATE FRAMEWORK CONDITIONS THAT INCENTIVIZE MARKET PARTICIPANTS TO FIND COST-EFFICIENT SOLUTIONS.

The task of market design is therefore to translate information about individual preferences into price signals and to incentivize a cost-efficient electricity system through system-friendly behaviour by consumers and investors.

# 5 Discussion of Capacity Mechanisms

UNINTENDED CONSEQUENCES

Capacity markets distort market allocation and price signals, and in dynamic markets, they tend to trigger a slippery slope of increasing overcapacity.

The objective of further developing the electricity market is to enable it to ensure security of supply in a cost-efficient manner while also addressing the challenges of the energy transition within an integrated system of incentives. In Chapter 2.2, we outlined several current challenges that need to be addressed in the ongoing debate on electricity market reform. Only some of these challenges can be addressed through capacity mechanisms. To assess the various capacity mechanisms, we draw on the evaluation criteria discussed in Chapter 3.

INFOBOX: MISSING MONEY

In political discussions, the term "missing money" is often used to suggest that electricity markets do not generate sufficient revenues to cover investment costs. From an economic perspective, however, there must be a compelling reason to justify market intervention. In the economic literature on capacity mechanisms, the missing money problem is frequently cited as a legitimate rationale for state intervention. However, this revenue gap typically refers to the existence of price caps. Such caps, introduced in some markets to limit the exercise of market power, structurally lead to under-recovery of fixed costs. Yet, these interventions can create further externalities that prompt additional market distortions. In Germany, however, no such price caps exist that would economically justify a market intervention.

The mere intention to increase revenues does not constitute a sufficient economic justification for intervening in the market. It is therefore necessary to analyse the underlying causes of insufficient revenues to identify sustainable solutions. For instance, if excess capacity exists in the electricity market, price levels will be too low to incentivise new investments. In such cases, it is economically appropriate that prices do not trigger further investments. As discussed in the previous chapter, insufficient demand-side flexibility – i.e. when consumers are unable to express their willingness to pay through price-elastic behaviour – may represent a relevant market imperfection.

The lack of markets can also be a reason for the revenue gap (e.g. incomplete ancillary services or futures markets or the lack of internalisation of external costs).

This "missing markets" concept indicates that incomplete markets can also be an approach for the targeted further development of the electricity market.

For example, incomplete markets for system services or hedging contracts – or the lack of internalisation of external costs – can result in revenue shortfalls. This “missing markets” concept suggests that the absence of certain market segments can themselves be a target for the purposeful development of the electricity market.

Depending on the specific imperfection identified, the appropriate responses for an incomplete market design may differ. Market reforms could include removing price caps and other distortions to improve price signals and thereby enhance revenue opportunities. Increasing demand-side flexibility and expanding storage capacity can also address structural market imperfections. Other countries complement their electricity markets with capacity mechanisms or other income-supporting measures.

Where a structural imperfection is identified, however, there is a spectrum of targeted options available. These interventions typically differ in their level of market distortion. It is not a sustainable strategy to address a market imperfection by introducing subsidies or support mechanisms. Such interventions inevitably trigger new consequences that require further adjustments over time – introducing investment uncertainty.

The goal of a sustainable market design should therefore be to resolve the root causes of market imperfections in a targeted manner. In doing so, the evolved electricity market can send appropriate incentive signals that enable security of supply to be achieved in a cost-efficient and environmentally sustainable way.

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The choice and design of an appropriate capacity mechanism is crucial for the success of the energy transition, as it sets the framework for investments. The specific product design of a capacity mechanism can either expand or restrict the solution space. Therefore, it is essential to implement a capacity mechanism that addresses the challenges as efficiently as possible while keeping the technological solution space open, in order to smoothly integrate future technological innovations into the electricity market.

THE GOAL OF A SUSTAINABLE MARKET DESIGN SHOULD BE TO ADDRESS MARKET IMPERFECTIONS AT THEIR ROOT.

When further developing the market design, it is therefore important to address specific challenges in sufficient detail while also taking a step back to keep the overall task in view. A sustainable market design must avoid overreactions that would create the need for future corrections and thus further regulatory intervention. Instead, the focus should be on establishing a fit-for-purpose incentive system that is capable of addressing the fundamental challenges of a dynamic, renewables-based electricity system. The market-based organisation of the transformation should be able to respond flexibly to emerging challenges and thereby ensure the sustainable development of the electricity system.

## 5.1 SELEKTIVE CAPACITY MECHANISMS

The primary feature of selective capacity support mechanisms is the pre-selection of specific technological characteristics that are to be promoted. As such, they are more accurately described as support schemes rather than market designs, since they incorporate competitive elements but exclude many key aspects of a market-based framework. The support objective may, for example, target specific technological features (e.g. combined heat and power) or particular fuels (e.g. hydrogen). In this context, the Power Plant Strategy ("Kraftwerksstrategie", KWS) represents a selective mechanism. We will therefore use the KWS as a reference point throughout this section to identify and discuss the core features of selective mechanisms.

- SCOPE/QUANTITY: A central authority determines the amount of capacity or energy volume to be procured. Selective mechanisms therefore only cover a limited segment of the market.
- TECHNOLOGICAL SELECTION: The contracting entity defines the desired technological characteristics in the eligibility criteria of the procurement process. If a specific technology or fuel is to be supported, the product design must necessarily be highly specific and detailed to ensure the policy goal is met.
- PROCUREMENT: The targeted technologies can be procured through auctions. The effectiveness of the measure depends significantly on the detailed design of implementation deadlines and penalty provisions.
- REMUNERATION: Auction winners typically receive support payments during the delivery period to incentivise investment. The effectiveness of the mechanism also depends on the specifics of the payment terms and penalty rules.
- INTERNAL MARKET: Selective mechanisms generally apply to the Member State running the auction. As such, they require state aid approval from the European Commission to ensure that distortion of the internal market remains limited.

- FUNDING: Selective mechanisms require price-exogenous funding, for example through the federal budget, dedicated support funds, or levies.

During the Green and White Paper process initiated by the BMWK about ten years ago (see BMWK, 2014 and BMWK, 2015), selective mechanisms were removed early on from the set of viable options, as they were deemed unable to ensure security of supply. Due to their selective nature, they tend to crowd out other technologies, which may subsequently be decommissioned. Moreover, a technological concentration can reduce the resilience of the power system.[30] Because of these distortions to market functioning, the impact on security of supply remains uncertain.

SELECTIVE MECHANISMS CANNOT ENSURE SECURITY OF SUPPLY, AS THEY CROWD OUT NON-SUBSIDISED TECHNOLOGIES.

It is therefore all the more surprising at first glance that the BMWK announced the Power Plant Strategy (KWS) less than ten years after reaching this earlier conclusion. However, there is at least one plausible explanation: ten years ago, the use of hydrogen for electricity generation was not yet a central part of the debate. The Russian war of aggression against Ukraine has made Germany's natural gas supply more risk-prone, more expensive, and likely more emissions-intensive (at least in the case of LNG from fracking). The motivation to accelerate the use of hydrogen is therefore understandable.

### Assumptions About the Allocation Task and Their Implications

The use of selective mechanisms is based on an implicit assumption: that there is no uncertainty about the required technology or the necessary primary energy carrier. As a result, neither competition nor market-based organisation is deemed necessary as a discovery or allocation mechanism. If this assumption holds true, prescribing the only sensible path may indeed be more efficient. However, many dimensions of the complex allocation task are disregarded in such an approach. For instance, even when there is strong certainty that a specific technology is required, it typically remains uncertain how much of this technology is actually needed.

[30] For example, low water levels can lead to cooling issues in the French nuclear fleet, limiting its availability for electricity generation. Similarly, electricity systems with a high share of hydropower can be negatively affected by periods of drought. In this sense, an undiversified reliance on fossil fuels or hydrogen-based energy carriers can also pose risks to security of supply.

Among the unintended consequences of selective mechanisms is the fact that they displace not only those technologies whose phase-out may be politically or environmentally acceptable (e.g. due to climate targets), but also those technologies that will be essential in the future. Supporting individual technologies inevitably reduces the economic viability of flexibility options in the market – such as storage technologies and flexible consumers. Consequently, selective mechanisms create externalities in the form of higher societal costs, for example through increased renewable energy support payments, since the displacement of flexibility options lowers the market value of renewable energy.

Even if a technology appears clearly necessary from a system perspective, the way it is incentivised plays a decisive role in a market-based allocation system. Technology-specific subsidies typically lead to path dependencies. As a result, investors who commit capital to this or similar technologies will expect continued support in the future and are unlikely to invest without it. This expectation reflects the long-term distortive effect of selective mechanisms.

EVEN IF A TECHNOLOGY SEEMS OBVIOUSLY NECESSARY, THE WAY IT IS INCENTIVISED PLAYS A CRUCIAL ROLE FOR SUSTAINABLE MARKET FUNCTIONING.

The environmental impact of selective mechanisms can only be assessed based on their specific design. In the case of the Power Plant Strategy (Kraftwerksstrategie), for example, it remains unclear when the use of hydrogen will become mandatory and whether this obligation will be upheld in the long term. Until then, natural gas will be used, and flexibility options are likely to be crowded out, which would have negative consequences for the integration of renewable energy sources.

The inherent tendency of selective mechanisms to crowd out other technologies creates a market entry barrier for new and innovative solutions. As a result, selective mechanisms almost inevitably lead to additional demands for support. On the one hand, it can be argued that these new technologies also offer value and therefore deserve comparable support on the grounds of fairness. On the other hand, their economic viability is negatively affected by the initial support for the first technology, which creates the need for further subsidies to re-establish a level playing field.

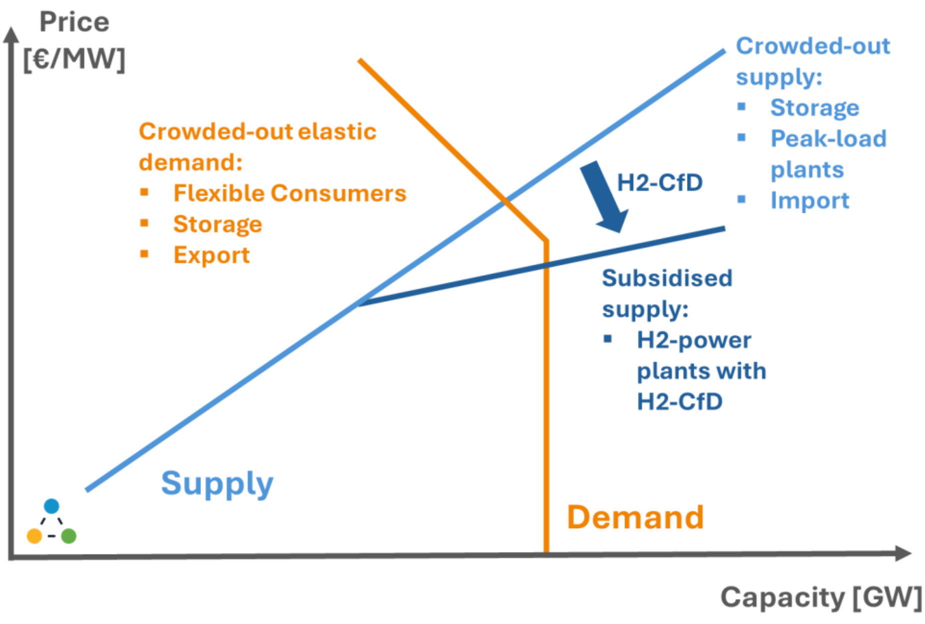
However, this does not resolve the underlying issue. Instead, it triggers a self-reinforcing cycle of support (the so-called oil spot theorem), in which each intervention leads to further distortions. These cumulative distortions drive up overall system costs and lead to support claims from an increasing number of technologies.

## EXCURSUS: THE IMPACTS OF HYDROGEN CONTRACTS FOR DIFFERENCE

In the context of the Power Plant Strategy (Kraftwerksstrategie – KWS), in addition to investment subsidies for capacity (EUR/kW), operational subsidies (EUR/kWh) through hydrogen Contracts for Difference ($H_2$-CfDs) are also being considered.

A common justification for $H_2$-CfDs is the uncertainty surrounding future hydrogen prices and the concern that fully passing through these high costs would result in elevated electricity prices. However, this argument overlooks a fundamental economic principle: risks and costs do not disappear when shifted elsewhere. Rather, their consequences materialise in a different location – typically where they are harder to manage effectively, such as for taxpayers or end consumers).

If the high cost of hydrogen is shielded from the power market through the price-distorting effects of $H_2$-CfDs, then hydrogen's role as a price signal for efficient resource allocation is eliminated. This leads to both operational and investment-related market distortions that increase long-term system costs. The following figure illustrates how this price distortion affects the allocation task, showing that more cost-efficient alternatives – such as storage, flexible consumers, or imports from the internal market – are displaced.




In the figure, it becomes clear that the operational subsidisation of hydrogen-fired power plants displaces other technologies.[31] $H_2$-CfDs reduce price volatility by

[31] Storage plays a role on both the supply and demand side. Its price-dampening effect is not limited to charging during periods of very low prices – typically caused by high levels of renewable generation – and discharging during scarcity

shifting hydrogen costs away from the market and into the federal budget or other funding mechanisms. This cost shift gives rise to externalities that manifest in multiple ways.

In day-to-day operations, the profitability of the displaced, more cost-efficient technologies declines, weakening their investment signals. Furthermore, these displaced technologies are exposed to increased uncertainty, as it becomes difficult to predict whether the $H_2$-CfD subsidies will be extended beyond the official support period.

As a result of this crowding-out effect, total system costs increase – both in the short and the long term. It is important to emphasise that what ultimately matters are the total system costs, not merely the specific costs of an individual measure. From a system perspective, it can be more cost-efficient to utilise a technology with lower capital costs – even if it leads to higher prices during operation – if that avoids the need for additional power plant investments. For example, it may be economically reasonable to rely on load flexibility that triggers high prices during a few peak hours, if this avoids investing in power plants that would only be needed for those few hours per year.

Political interventions in the dispatch behaviour of technologies already participating in the market are problematic from a market-based perspective. During the debate on the reform of the European electricity market design, there was a proposal to abolish the merit order and split the market. This interference with the organisation of the electricity market was rightly not implemented. However, the introduction of $H_2$-CfDs effectively simulates such a segmentation by suppressing scarcity signals that would otherwise emerge under full cost pass-through of hydrogen.

By promoting domestic generation, $H_2$-CfDs also distort the internal market by displacing more cost-efficient generation in other Member States. This displacement can reduce imports of cost-efficient electricity. Conversely, subsidised German electricity may be exported, further undermining the profitability of foreign technologies.

In addition to the rise in total system costs, the question arises as to who bears the financial risk associated with the uncertainty of future hydrogen prices. From an investor's point of view, it is often argued that the state should assume this risk if

situations. Storage also contributes to cost-efficient outcomes in tight market conditions by charging even at high prices and discharging in even scarcer situations, which may involve extreme price spikes. In doing so, storage can also make use of price volatility during high-price periods to enhance overall market efficiency.

the investments are politically desired. However, from the perspective of the state – especially given increasingly scarce public funds – it becomes difficult to justify absorbing this financial risk through the federal budget or dedicated funding schemes.

$H_2$-CfDs are intended to equalise the cost gap between gas-fired power generation (including $CO_2$-costs) and hydrogen-based generation. Especially during the ramp-up phase of the hydrogen market, however, market liquidity will be low, and hydrogen prices are therefore expected to be highly volatile. Yet the $H_2$-CfD effectively removes the $H_2$-price as a relevant input for dispatch decisions. If, for example, the hydrogen price were to multiply due to a disruption in global supply chains, hydrogen would still be used for electricity generation, as the CfD eliminates any price signal that might otherwise constrain its use.

As a result, hydrogen demand becomes inelastic. That means hydrogen is burned for electricity regardless of its market price. Electricity consumers, in turn, also do not react to the high hydrogen costs, as the electricity price is suppressed by the $H_2$-CfD and thus disconnected from the true cost of supply. Electricity is therefore consumed at a subsidised price, decoupled from the value or utility of that consumption.

Without market-based feedback mechanisms, the cost of this subsidy scheme could theoretically become unlimited. This poses a significant fiscal risk, which cannot be absorbed indefinitely by the federal budget or dedicated funding instruments.

Capping the subsidy to prevent disproportionate cost burdens may seem like a sensible solution. However, doing so would shift the risk of high hydrogen prices back onto the plant operator. This, in turn, either increases the cost of capital or leads to investor reluctance. The risk itself cannot be eliminated – it can only be shifted. It must either be borne by investors, who are generally equipped to manage such risks, or by the public in one form or another.

Should hydrogen prices remain high beyond the end of the CfD support period, it is likely that the subsidy will be extended to avoid a sudden and politically sensitive spike in electricity prices. Phasing out subsidies is always challenging from a political-economic perspective. But if the expiry of support mechanisms results in noticeable electricity price increases for the broader population, it becomes even more unlikely that they will be allowed to lapse.

Nonetheless, the cost gap must be covered. This creates both a path dependency in favour of continued support and an enduring uncertainty for market actors – namely, that their investments may become unprofitable once the CfD ends.

The assumption that policymakers possess sufficient information to override the allocation and discovery functions of markets can result in significant additional costs, both in the short and long term.

In political discourse, it is often assumed that support for a particular technology must go hand in hand with its financial promotion, and that scepticism about subsidies is synonymous with opposition to the technology itself. However, there is a crucial difference between the "if" of a technology and the "how" of its integration into the market or its entry pathway.

In the context of the Power Plant Strategy (KWS), this means that the likely need for new gas-fired power plants does not automatically justify subsidies under the label of a "no-regret" decision.[32] Even if a technology is economically or systemically sound, the chosen form of support can still lead to political-economic "regrets" due to the path dependencies it creates. Hydrogen-fired power plants may indeed play an important role in ensuring security of supply – but the key question is how they are incentivised.

For a viable technology, a more sustainable approach is to improve the framework conditions in such a way that its economic viability improves structurally. Ideally, these improved conditions will reduce or eliminate the need for subsidies that are inherently associated with uncertainty.

Interventions in the market's allocation function typically entail unintended consequences – consequences that must themselves be addressed. For this reason, even in the case of seemingly "no-regret" technologies, it is essential to consider potential unintended side effects, such as path dependencies, that may result from the design of support schemes".

### Effects on Market Concentration

In its most recent market power report for the electricity sector, the German Federal Cartel Office (Bundeskartellamt, 2023) found that one company in Germany clearly exceeds the presumption threshold for market dominance, while two other companies are approaching this threshold.[33] According to the

[32] The term 'no-regret' refers to a measure that is beneficial under all circumstances – regardless of how future developments unfold.

[33] The presumption threshold is merely an indicator of potential market power based on market share in specific market situations. It does not provide any evidence as to whether companies actually exploit this potential market power.

Cartel Office, the decommissioning of power plants by other producers tends to further increase the potential for market power.

With regard to the impact of selective mechanisms, it is worth examining how such mechanisms might affect future market concentration. Larger companies typically possess more extensive market information than smaller ones, which can improve their competitive position in procurement processes. In addition, they are more likely to exert political influence to shape tender conditions to their advantage.

While this outcome is not inevitable, it is nonetheless plausible that the Kraftwerksstrategie (Power Plant Strategy) could lead to an increase in market concentration in Germany.

### Political-Economic Aspects of Selective Mechanisms

Selective mechanisms are often originally designed with a high degree of precision from an academic or technical perspective, with the aim of achieving the intended policy objective as accurately and cost-efficiently as possible. However, during the legislative process, these mechanisms are frequently modified as a result of the political discourse involving national and European stakeholders, as well as lobbying efforts by interest groups (rent seeking).

The Kraftwerksstrategie (Power Plant Strategy) offers a number of illustrative and representative examples of how a selective mechanism can evolve throughout the political design process.

#### EXCURSUS: A BRIEF HISTORY OF THE POWER PLANT STRATEGY

The appeal of a selective instrument lies in its seemingly minimal-invasive and timely implementation to target specific aspects of the system. The following excerpts from four press releases issued by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) illustrate how the Power Plant Strategy (KWS) evolved throughout the political design process:

- 01 FEBRUARY 2023: SECURING RELIABLE POWER SUPPLY THROUGH THE END OF THE DECADE
  "To this end, we will present a power plant strategy in the first half of this year to ensure the construction of the power plants needed for a climate-neutral electricity system."

- 09 MARCH 2023: “RENEWING PROSPERITY IN A CLIMATE-NEUTRAL WAY” – HABECK PRESENTS PROGRESS REPORT
  “A ‘Power Plant Strategy’ will be developed by summer 2023. There is a need for the construction and modernisation of controllable capacity amounting to 17 to 25 GW by 2030. The power plants are to be capable of using hydrogen.”
- 01 AUGUST 2023: FRAMEWORK FOR THE POWER PLANT STRATEGY ESTABLISHED – IMPORTANT STEPS ACHIEVED IN TALKS WITH EU COMMISSION ON HYDROGEN POWER PLANTS; CONSULTATION PHASE AND FORMAL STATE AID PROCEDURE TO FOLLOW
  “The shared understanding for the next steps includes key components and framework conditions for the upcoming measures. These form the guiding parameters within which the state support programmes must operate in order to comply with European state aid and energy law. The next step will be a consultation phase, starting at the end of summer 2023. During this phase, the state aid procedure with the European Commission will also continue.” [...]
  “Specifically, we plan to tender 8.8 gigawatts of new power plants to be operated with hydrogen from the outset. In addition, up to 15 gigawatts of hydrogen power plants are to be tendered by 2035, which may initially be operated with natural gas until connected to the hydrogen network, but no later than 2035. Of these 15 gigawatts, we intend to tender 10 GW by 2026 in a first step, followed by an evaluation before the remaining 5 GW may be tendered.”
- 05 FEBRUARY 2024: AGREEMENT ON THE POWER PLANT STRATEGY
  “It was agreed that work on the future electricity market design will be promptly advanced and that, in particular, concepts for a market-based, technology-neutral capacity mechanism will be developed to be operational no later than 2028.” [...]
  “Specifically, the Federal Chancellor, the Federal Minister for Economic Affairs and Climate Action, and the Federal Minister of Finance have agreed that new power plant capacities of up to 4 × 2.5 GW will be tendered as $H_2$-ready gas-fired power plants under the power plant strategy. These plants shall fully convert to hydrogen between 2035 and 2040, with a switch-over date to be determined in 2032. The plants are to be located at system-relevant sites.” [...]
  “To support the development of new technologies (e.g. nuclear fusion) and to trial the operation of power plants, these will be funded using suitable instruments. Power plants running exclusively on hydrogen will be supported with up to 500 MW under the energy research programme.”

The selection of press statements illustrates that over the course of the process, the timeline, scale, technological composition, and the transition period to hydrogen have all changed.[34] Furthermore, the targeted approach was made conditional upon the introduction of an additional “market-based, technology-neutral capacity mechanism.”

At the time this study was conducted, the Power Plant Strategy remains under discussion with the European Commission. However, it is questionable whether the Commission will be able to approve the spatial allocation of the plants and the extended use of natural gas under Article 4.1 of the State Aid Guidelines (2022) for the promotion of climate-neutral electricity generation.

Even if the European Commission approves the measure, the question remains whether this agreement provides sufficient legal certainty for investors. It is likely that environmental organisations will challenge the approval of subsidies for fossil-based power generation under the state aid provisions for climate-neutral electricity generation at the European Court of Justice. This legal uncertainty affects investment decisions and the pace of project implementation.

There may well be differing opinions as to whether the original design of the Power Plant Strategy (KWS) was appropriate. Such assessments likely depend on the role one envisions for hydrogen in the future electricity system. However, it is clear that the original version of the KWS and its application for state aid approval were internally consistent. Over the course of the political process, however, all key elements of the KWS have changed: the volume of immediate hydrogen-fired power plants, the volume of hydrogen-ready plants, and their transition timeline.

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One might be inclined to think that the Power Plant Strategy (KWS) is an exception. However, the complications discussed in its design – as well as the unintended consequences of selective mechanisms – were already well documented ten years ago (see e.g. Connect, 2014).

The original intention of the KWS was to support the use of hydrogen in electricity generation. But selective mechanisms tend to trigger additional demands. Various stakeholders are now seeking to expand the scope of the KWS – for example, by integrating combined heat and power (CHP), biogas, batteries, flexible consumers, and other additions.

Moreover, the debate around subsidising specific technologies often results in delayed investment decisions (a phenomenon known as wait-and-see behaviour or attentism) until the details of the support scheme are clarified.

[34] The European Taxonomy Regulation requires a switch to hydrogen (or low-emission gases) by 2035 at the latest. If the transition in the power plant strategy were to take place at a later date, this would raise additional questions regarding financing conditions.

This, in turn, exacerbates the very problem the measure was intended to address (see the discussion on misaligned and distorted incentives in Section 2.3.1).

From a political perspective, selective mechanisms are tempting because they appear to be minimally invasive and therefore easy to implement quickly and with targeted precision. However, in both political and economic reality, they are often accompanied by a wide range of unintended consequences. These include, for example: the crowding out of other desirable technologies and innovations, the creation of path dependencies, an increase in total system costs in both the short and long term, a failure to deliver the intended impact, and structural inertia that makes the phase-out of the measure difficult.

## 5.2 CAPACITY RESERVE

The German capacity reserve represents a specific form of a strategic reserve. Consequently, the discussion largely focuses on the details of this concrete implementation. The objective of the capacity reserve is to ensure a secure electricity supply even in the event of a market non-clearing situation on the wholesale market – without distorting the market.[35] It serves as a complementary option for market designs in which competitive electricity markets are expected to incentivise investment in dispatchable capacity.

Unlike other forms of strategic reserves, the capacity reserve is specifically designed to avoid any market distortion by only being activated when the market fails to clear and only after all balancing reserves have been exhausted (pursuant to Section 13e of the German Energy Industry Act [EnWG] and the Capacity Reserve Ordinance [KapResV, 2019]).

- SCOPE/QUANTITY: Unlike other forms of strategic reserves, the dimensioning of the capacity reserve requires only a small amount of capacity, as it is designed solely to ensure supply in the event of a market non-clearing. The resulting scarcity signal is intended to incentivise all available technologies to contribute to market clearing.
- TECHNOLOGICAL SELECTION: Ideally, the technologies used should be able to start quickly. Thermal power plants, storage systems, and interruptible loads are permitted. Slower technologies increase the operational management requirements to maintain neutrality in the electricity market (similar to redispatch measures).

[35] Market clearing occurs when each demand bid without a price limit can be matched with available supply. If supply is insufficient to meet demand at any price, the market does not clear.

- PROCUREMENT: The capacity reserve should preferably be provided by existing installations that are exiting the market. To mitigate market power and limit costs, new installations may also be allowed to participate in the tendering process.
- REMUNERATION: Successful bidders are paid for the provision of capacity. In addition, their variable costs are compensated.
- INTERNAL MARKET: To ensure supply within a bidding zone, the reserve capacity should be located within that zone. However, since it is only activated as a last resort, the internal market is not distorted, as all other available options (including imports) must be exhausted first.
- FUNDING: The reserve is currently financed through network charges.

The capacity reserve is typically procured from existing plants that have been scheduled for decommissioning. After being used as part of the capacity reserve, these plants are not permitted to return to the market; instead, they must be permanently decommissioned. In this respect, the capacity reserve differs from capacity incentive instruments, which are designed to increase the volume of capacity available in the market.

The capacity reserve functions as an insurance mechanism against uncertain events that may compromise security of supply. By definition, market participants cannot prepare for such unforeseeable events. In such cases, the capacity reserve is intended to safeguard electricity supply.

THE CAPACITY RESERVE ALSO SERVES AS AN INSTITUTIONAL SAFEGUARD FOR THE MARKET DESIGN, THEREBY INCREASING THE CREDIBILITY OF PRICE SIGNALS.

However, the capacity reserve also serves as an institutional safeguard for the market design. In the event of a supply disruption, it can be expected that a political debate would arise regarding a potential adjustment to the electricity market design. As discussed in Section 2.3.1, such political uncertainty can lead to investment hesitation. This would undermine the incentive effect of price signals, thereby exacerbating the scarcity situation in the electricity market. By preventing supply disruptions, the capacity reserve therefore also protects the integrity of the market design, reinforcing the credibility and effectiveness of price signals.

The direct environmental impact of $CO_2$-emissions resulting from the activation of the capacity reserve is negligible due to the small volumes involved. Its positive environmental contribution is realised indirectly through the safeguarding of price signals, which supports the incentive effect for increased flexibility in the electricity market.

### Focus on Distortion-Free Security of Supply

The primary objective of the capacity reserve is to ensure a cost-efficient[36] and largely distortion-free safeguard of electricity supply, in order to allow the market's price signals to unfold their full incentive effect. To achieve this, it is necessary to accept the apparent inefficiency of an insurance premium by maintaining power plants outside the electricity market.

Occasionally, the risk is raised that the capacity reserve could grow over time, increasing its inefficiency. However, this risk does not apply to a capacity reserve as such, but rather to a strategic reserve that would be activated at a relatively low market trigger price. A low trigger price would act as an implicit price cap, thereby creating a classic missing money problem. The investment signal would be suppressed, and power plants would structurally receive insufficient incentives to remain in the market and would subsequently exit. These power plants would then be absorbed by the strategic reserve, which would gradually increase in size.

However, this risk of growth does not apply to the current design of the German capacity reserve, as it is only activated outside the market.[37] As a result, wholesale electricity prices and balancing energy prices can fully unfold their incentive effects. Currently, the balancing energy price would rise to EUR 20,000/MWh in situations where the capacity reserve is activated (BNetzA, 2023b). This price signal would create strong incentives both for expanding supply and for increasing demand-side flexibility.

Similar to the first occurrence of a negative price spike of –500 EUR/MWh in 2009 (see discussion in Section 4.2 a significant positive price spike would trigger numerous adjustment processes: on the one hand to benefit from high revenues, and on the other hand to avoid high costs. If market participants perceive the regulatory framework as stable – as was the case following the 2009 price event – these price signals will be followed by a wide range of adaptations. In the short term, this could include adjusting maintenance schedules and retrofit periods, as well as renegotiating contracts with flexible consumers to utilise flexibility potential more efficiently. Depending on the price structure and expectations of future scarcity, investors may also be incentivised to invest in short-term storage or new generation capacity. In other words: the incentive signals of an efficient market would take effect.

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[36] In 2022, €70.9 million were spent on the capacity reserve.

[37] At present, the capacity reserve is authorised under state aid guidelines for up to two GW. For the second provision period (1 October 2022 to 30 September 2024), only 1,086 MW were procured.

### Political-Economic Balance

From a political-economic perspective, the capacity reserve is, on the one hand, unattractive because it remains outside the market even in scarcity situations where market clearing is still taking place, and therefore cannot be used to lower prices. On the other hand, it can be viewed as an insurance mechanism against supply interruptions, which conveys prudence and responsibility.

Allowing the reserve to grow would be politically unpopular, as the increasing cost of maintaining the capacity would stand in contrast to an uncertain or infrequent benefit. In light of this trade-off, the capacity reserve proves to be a relatively stable instrument that does not create political incentives for distortion.

## 5.3 CENTRAL COMPREHENSIVE CAPACITY MARKETS

Central comprehensive capacity markets differ structurally from the approaches discussed thus far. Their goal is to cover the entire market and integrate all technologies.[38] However, they do not constitute a market-based approach but rather a competitive measure, as they pre-empt or at least limit many allocative decisions. Typically, capacity markets covering the full market are dimensioned based on peak load. In the course of this section, we will discuss why such an approach to dimensioning would not be appropriate in the German electricity market and which challenges would result from it.

The discussion of central capacity markets is somewhat more extensive, as their incentive effects differ from those of other approaches and several design elements require explanation. The extensive insulation from market-based risks and the long-term payment guarantees found in European capacity markets resemble characteristics of subsidy schemes more than those of market design. A sound market design is defined by targeted incentives that lead to cost-efficient demand coverage. In contrast, support schemes shield individual technologies, groups of technologies, or market participants from risk and ensure sufficient remuneration (see infobox on the tasks of market design in Chapter 3).

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[38] From 2025 onwards, high-emission assets will no longer be eligible to participate in capacity mechanisms. An exemption could apply until 2028. However, if a capacity market were introduced in Germany no earlier than 2028, coal-fired power plants would likely no longer be eligible to participate. It therefore remains unclear how 'market-wide' the design of a capacity market could truly be as long as coal-fired power plants continue to operate within the electricity market in Germany.

There is a wide range of design approaches for capacity markets. In this section, we primarily refer to European models and consider the legal requirements of the EU.

- SCOPE/QUANTITY: A central authority determines the total capacity to be auctioned. Since capacity markets are designed to cover the entire market, they are usually dimensioned according to historical peak load or forecasts of future peak load.
- TECHNOLOGICAL SELECTION: In principle, all prequalified technologies may participate in the capacity auction. However, centrally defined derating factors determine the proportion of the capacity payment that each technology is eligible to receive. Market segmentation through auctions with different lead times before the delivery period allows participation of technologies with varying characteristics. According to the EU Electricity Market Regulation (2024), technologies emitting more than 550 g $CO_2$/kWh or more than 350 kg $CO_2$/kW will be excluded from capacity mechanisms as of 2028. This excludes coal-fired power plants without CCS from participation beyond that date.
- PROCUREMENT: Technologies and capacity prices (adjusted by derating factors) are determined through auctions. In the US, auctions typically take place three years before the delivery period (Y-3). In the UK and Belgium, the main auction is held four years ahead (Y-4), with a second auction held one year before delivery (Y-1). A portion of the total volume is reserved for this second auction (in Belgium, the volume required to cover the 200 highest demand hours). The Y-1 auction allows updates to the total capacity volume and derating factors. From 2025, Belgium will introduce an additional Y-2 auction to further segment procurement. Capacity markets may include bidding limits – for instance, the Belgian market sets different bid caps for existing versus new installations.
- REMUNERATION: Successful bidders receive the auction-determined capacity payment, scaled by their respective derating factors. Contracts typically cover a single delivery year. However, in Belgium, bids for 3-, 8-, or 15-year delivery periods are permitted. New assets can prequalify for up to 15 delivery years. Existing assets requiring retrofits can qualify for up to 3 or 8 years, depending on the level of investment required and demonstrated with financial documentation.
- INTERNAL MARKET: Cross-border capacity can participate, though typically with higher derating factors due to the uncertainty introduced by interconnector flows (Acer, 2020). In the UK, interconnectors can participate directly, and their derating factor is calculated based on modelling results.

- FUNDING: A price-exogenous form of funding is required. This may be provided through the federal budget, dedicated funding programmes, or levies.

In order to obtain state aid approval for the introduction of capacity markets, the EU Electricity Market Regulation (2024) and the EU Electricity Market Directive (2024) specify a range of design requirements. For example, capacity markets must be technology-neutral and open to foreign capacities from other Member States.[39] While these requirements are formally met in the capacity mechanisms approved to date, gradual discrimination against certain technologies and cross-border assets is unavoidable – for example, through the application of derating factors. Compared to a competitive electricity market, this leads to preferential treatment for certain technologies within a Member State.[40]

To ensure the intended effectiveness of capacity markets, a broad range of detailed rules must be established and monitored. These include:

- Prequalification criteria
- Financial documentation
- Monitoring and enforcement of project schedules and technical specifications
- Testing of installations
- Penalty mechanisms in the event of non-compliance

A full discussion of all these elements and their interactions is beyond the scope of this study. However, to understand the essential mechanics of central capacity markets, it is important to examine selected elements in more detail. In the following section, we do so by drawing on examples from the UK and Belgium and by assessing their alignment with the principles of a sustainable market design, as developed in Chapter 4.

### Penalisation and Effectiveness

Capacity markets require a careful trade-off between ensuring their effectiveness and avoiding an excessive increase in investment risk. A parallel can be drawn to Germany's offshore wind auctions, where it is sometimes criticised that the awarding of seabed areas merely constitutes an option,

[39] For example, this provision could make it possible for French nuclear power plants to receive support through a German capacity market.
[40] See e.g. Gramlich et al. (2019): Too much of the Wrong Thing: The Need for Capacity Market Replacement or Reform.

without any binding obligation to build. This can weaken the overall effectiveness of the mechanism.

To ensure that capacity markets reliably contribute to security of supply, penalty mechanisms are introduced in case of non-availability of contracted capacity. The logic is straightforward:

A CENTRAL AUTHORITY DETERMINES THE EFFECTIVENESS AND COST OF THE CAPACITY MARKET THROUGH THE RULES AND LEVEL OF PENALISATION.

- Higher penalties lead to greater availability, as market participants have a strong incentive to ensure that their capacity is operational.
- However, higher penalties also increase investment risk, particularly for smaller market actors. This risk is reflected in higher bid prices, ultimately raising the cost of the capacity market.
- If penalties are too low, the investment environment becomes more attractive, but availability declines and the effectiveness of the capacity mechanism suffers.

This creates a classic policy trade-off between cost and reliability. It is therefore the responsibility of a central authority to calibrate the penalty regime in such a way that it strikes a reasonable balance between:

- Ensuring capacity is available when needed
- Maintaining investor confidence
- Avoiding excessive costs for consumers
- Ensuring fair access for smaller or innovative market participants

Ultimately, the penalty structure plays a crucial role in defining the cost-efficiency and resilience of the entire capacity mechanism. But the penalty framework is not the only determinant of the cost and effectiveness of capacity markets – other elements such as force majeure clauses and the treatment of regulatory changes also play a critical role.

In addition to setting penalties, a central authority must define exceptions for force majeure events. If a capacity provider is unavailable due to circumstances beyond their control – as defined under force majeure – they may be exempt from their delivery obligation and from penalties. A key question in this context is what types of supply chain disruptions qualify. The stricter the definition, the higher the risk exposure for investors, which will be reflected in their capacity bids. Therefore, the force majeure definition directly impacts both the effectiveness and the cost of the capacity mechanism.

Furthermore, additional rules may be needed to account for regulatory changes that affect market conditions after bids have been submitted. Capacity bids are based on investors' expectations of future market conditions. If those conditions change – e.g., due to changes in bidding zones, renewable energy deployment, or emissions trading rules – there may be grounds for compensation negotiations between operators and the central authority.

This issue is particularly relevant in the case of a switch from natural gas to hydrogen. If the hydrogen price does not evolve as expected, or if government funds for operational support prove insufficient, changes in the conversion timeline or the nature of support schemes may be required. Consequently, investor confidence depends heavily on how compensation mechanisms are designed and how legal disputes over compensation are resolved.

Since capacity markets involve the state taking on responsibility for the organisation of security of supply, a wide range of parameters must be defined that – taken together – determine the level of investment risk, the overall investment climate, and the mechanism's effectiveness. Ongoing adjustments are typically required to reflect changing conditions. However, each adjustment can increase regulatory uncertainty for investors, which is reflected in higher risk premiums in capacity bids. As a result, even seemingly minor changes can lead to unintended consequences that must then be addressed through bilateral negotiations.

Whether a capacity market is suitable for a given electricity system also depends on the stability of its regulatory and market framework. Capacity markets are therefore not well suited for systems undergoing dynamic adjustment processes. In phases of structural transformation, continual recalibrations are needed. These adjustments can lead to significant additional costs and impair the effectiveness of the capacity market.

### The Impact of Derating Factors on Technological Neutrality

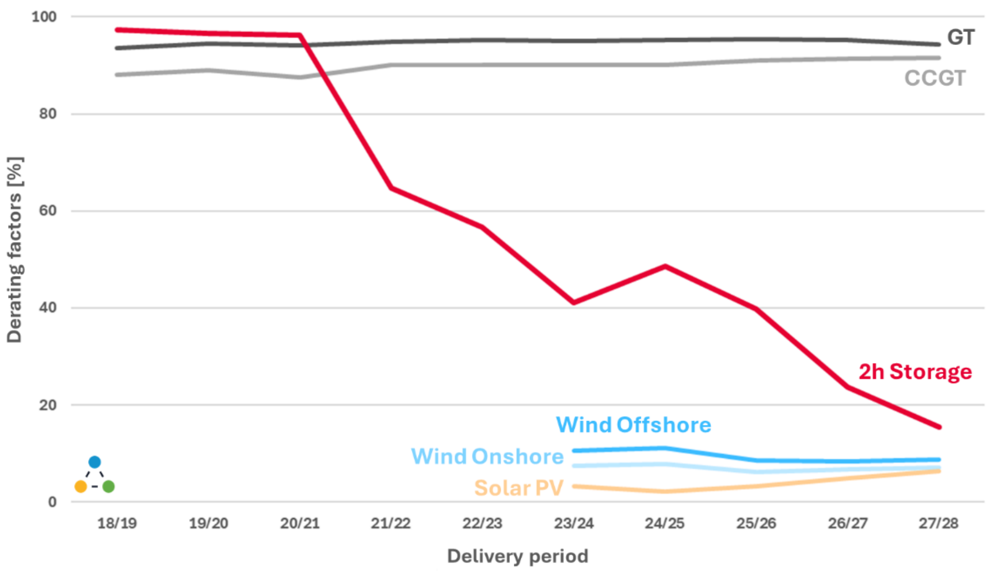
Policies should not be judged by their stated objectives, but by their actual effects. In assessing how capacity markets affect technological neutrality in the electricity sector, it is essential to understand the role of derating factors.

Technologies differ, among other things, in their availability and their contribution to security of supply. While centralised capacity markets are, in principle, open to a broad range of technologies, remuneration is differentiated through the application of derating factors.

Derating factors are technology-specific percentages that reflect the value a given technology provides to security of supply. When administratively determining these factors, a distinction is made between thermal power plants and other technologies with limited availability (e.g. storage, renewables, demand-side flexibility, and cross-border capacities).

The derating factor for thermal power plants is typically calculated based on historical availability – consistent with the method used in earlier capacity adequacy assessments (see discussion in Section 4.3). In contrast, the derating factors for other technologies are derived from probabilistic modelling that estimates their contribution to security of supply. The valuation of these technologies thus depends on model-based calculations, which in turn rely on inherent modelling assumptions and administrative parameters (see discussion in Section 4.1). Figure 18 illustrates the technology-specific derating factors in the UK capacity market over time. The Y-axis shows the derating factors, while the X-axis indicates the delivery period.

*Figure 18: Temporal Development of Selected Derating Factors in the UK Y-4 Auction*




*Source: Own illustration, data from National Grid (2014-2024).*

The illustration shows that variable renewable energy sources tend to have structurally lower derating factors than thermal power plants. This reflects their limited availability of primary energy. In contrast, the derating factors for thermal power plants are typically higher due to their more predictable and controllable output.

An interesting effect becomes visible with storage technologies. As illustrated, the derating factor for two-hour battery storage has decreased over time. This is because, in probabilistic modelling, the marginal contribution of storage to system adequacy diminishes as the penetration of storage increases. In early system configurations with limited storage capacity, each additional storage unit contributes significantly to avoiding supply shortages. However, as storage becomes more widespread, the model results reflect a declining marginal benefit, leading to lower derating factors.[41]

The economic relevance of derating factors encourages political influence. Because derating factors have a direct impact on the revenues technologies can earn in capacity markets, they create strong incentives for stakeholders to lobby for more favourable treatment of their preferred technologies – a classic case of rent seeking. This underscores the importance of critically assessing not only the technical rationale behind derating factors but also the political-economic dynamics they can trigger.

These technology assessments raise fundamental questions about market organisation and the incentivisation of security of supply. The determination of derating factors is based on model simulations that incorporate a wide range of explicit and implicit assumptions. These assumptions are administered by a central authority and are influenced by the political negotiation processes involved in defining the input scenarios. While the political process may shape the explicit assumptions (e.g. weather years, technology costs, demand projections), the implicit assumptions embedded in the model structure (e.g. perfect foresight, market behaviour, risk neutrality) remain unaffected.[42]

THE CENTRALLY DETERMINED EXPLICIT AND IMPLICIT MODELLING ASSUMPTIONS INFLUENCE THE ECONOMIC VIABILITY OF TECHNOLOGIES VIA THE DEFINITION OF DERATING FACTORS, AND THUS AFFECT THEIR FUTURE DEPLOYMENT.

The resulting model outcomes form the basis for setting derating factors, which in turn define the competitive economic conditions for different technologies in the capacity market. Consequently, these administrative choices lead to structural investment incentives – or disincentives – that shape the long-term

[41] With regard to the derating factors for storage, it is important to note that at the time the capacity market was introduced in the UK, there were no large-scale storage capacities, and the UK had less interconnector capacity than Germany. Due to the high flexibility needs in the UK, the added value of additional storage was initially relatively high. If a capacity market were to be introduced in Germany no earlier than 2028, the cumulative storage capacity would already be significantly larger. As of June 2024, nearly 10 GW of storage capacity with over 14 GWh of energy storage has been installed across all segments – utility-scale, commercial, and residential – according to Battery Charts (2024). It can therefore be assumed that the derating factors for storage in Germany would start at a significantly lower level than in the UK.

[42] As already noted in the discussion in Section 4.1, the long-term scenarios published by the BMWK have repeatedly given rise to debate – particularly because certain technologies, especially storage, are perceived by some stakeholders as being consistently underrepresented.

development of the generation mix. This effectively locks in certain pathways of technological development, raising questions about the openness of the market and the ability of price signals to efficiently guide the allocation of resources.

When companies use power market models to assess the profitability of investment options, this is a legitimate approach, as they combine their own expectations about the future with their risk preferences and bear the economic consequences themselves (“skin in the game”). However, when a central authority influences the value of individual technologies based on uncertain future expectations and assumptions, this approach entails elements of central planning, which are prone to misallocations. After all, the quality of the modelling assumptions – and thus of the derating factors – depends, among other things, on the quality of the available information regarding future developments. In practice, such forecasts tend to involve a high degree of uncertainty and are often subject to conservative determinations, especially under political influence.

In a competitive power market, there are no predefined earning potentials for individual technologies. There is only the opportunity – and the incentive – to increase revenues by maximising the respective technological contribution to meeting demand.

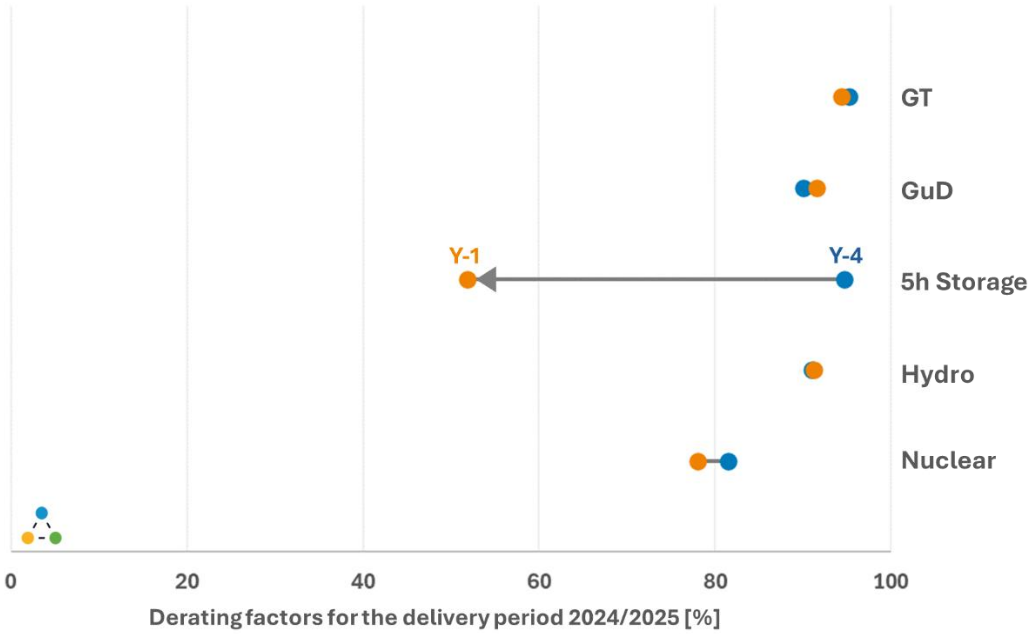
### Obstacle to Flexibilisation

A declining derating factor for storage means that remuneration in the capacity market also decreases accordingly. However, the impact of capacity markets on storage technologies is multifaceted. From a political-economic perspective, there are incentives in capacity markets to procure too much capacity rather than too little. While additional dispatchable capacity directly increases the costs of the capacity market and thus the overall system costs, overcapacity[43] also distorts prices on the power market. For example, price volatility is reduced. In a situation where flexible consumers might have set the price, thermal power plants (potentially subsidised via $H_2$-CfDs) now set the price instead. For storage operators, the artificially reduced price volatility lowers revenue potential on the power market (second-order effect). In addition, their derating factor in the capacity market declines (first-order effect), reducing revenue potential there as well. Compared to a purely competitive capacity mix, this distortion and the resulting path dependencies lead to higher overall system costs.

[43] See e.g. Aagaard et al. (2022): Too much is never enough: Constructing Electricity Capacity Market Demand.

However, the derating factor for storage does not only depend on the delivery year in which the storage unit enters the market. It also matters in which auction the contract is awarded. Figure 19 illustrates the different derating factors in the Y-4 and Y-1 auctions in the UK for the same delivery period (2024/2025).

*Figure 19: Change in Derating Factors Between the Y-4 and Y-1 Auctions for Delivery Period 2024/2025*




*Source: Own illustration, data from National Grid (2020 and 2024).*

Figure 19 clearly illustrates the change in derating factors between the two auction dates for the same delivery period. The decline in the derating factor for storage means that a 5-hour storage facility that did not participate in the Y-4 auction can only earn about half as much in the Y-1 auction, even though it starts operation in the same delivery period. In a competitive electricity market, the value of an asset is based on the actual service it provides – not on the timing of its approval, its market entry, or an administrative decision.

This raises the recurring question of market organisation. As previously discussed, the model results – and therefore the derating factors – depend, among other things, on the quality of assumptions about future developments. The fact that, for the same delivery period, the derating factor for a given technology can nearly

THE QUALITY OF THE ASSUMPTIONS MADE BY THE CENTRAL ENTITY REGARDING FUTURE DEVELOPMENTS AFFECTS THE PROFITABILITY OF TECHNOLOGIES THROUGH THE DERATING FACTORS.

halve provides an indication of the quality of these assumptions and the ability of a central entity to forecast future developments. However, the quality of administratively defined assumptions is crucial for the economic development of participating technologies in electricity markets with capacity mechanisms.

Since derating factors also depend on storage duration, experience in the UK has shown that some providers offer only part of their capacity in order to obtain a higher derating factor by presenting a more favourable ratio of capacity to storage duration. For example, in the most recent Y-4 auction in the UK, batteries could earn up to 35% more by bidding as a 9-hour battery instead of a 1-hour battery, even though they provide the same output to the (electricity) market (Modo Energy, 2024).

As a result, the capacity remuneration of a storage unit depends on a number of regulatory factors that are not necessarily related to its system value but instead derive from model calculations (partially driven by explicit and implicit assumptions), the timing of the bid, and bidding strategies. In a sustainable electricity market design, the profitability of a technology should be determined by the actual value it provides to the system rather than by regulatory interactions. This is particularly relevant for technologies that play a critical role in the economic viability of renewable energies. The goal of a sustainable market design is to integrate the value of system components in addressing the various challenges of the energy transition in order to minimise total system costs.

### Flexible Consumers

Compared to unconventional flexibility options, storage systems are relatively easy to integrate into capacity markets. The heterogeneity of flexible consumers, however, means that they cannot be appropriately incorporated into standardised capacity products (see the discussion on flexible consumers in Section 4.5). This does not mean, however, that they do not make relevant contributions to security of supply. On the contrary, as discussed, they are essential to the resilience and even the antifragility of the electricity system.

It is only due to the inherent limitations of administratively defined capacity product design that flexible consumers cannot be adequately considered in capacity markets. In competitive electricity markets, no such regulatory restrictions exist. If a technology can provide value in a given situation, it can participate in the long-term markets, spot market, or balancing market, taking into account its preferences and capabilities. Only the balancing markets define technical requirements to ensure system security. Yet these very requirements can be ideally met by many flexibility options, especially when aggregated into virtual power plants.

In addition to the explicit exclusion of flexible consumers, an implicit crowding-out effect also occurs. From a behavioural economics perspective, losses weigh more heavily on individuals than equivalent gains bring joy – a concept known as "Prospect Theory" (Kahneman and Tversky, 1979). When applied to consumer preferences, this insight suggests that the motivation for flexible behaviour – such as participating in dynamic pricing schemes – may be driven more by the desire to avoid price spikes than by the opportunity to benefit from low electricity prices.

By incentivising overcapacity and thereby reducing price variability, centralised capacity markets also reduce the motivation for flexible consumption behaviour. As a result of their distorting effect on price signals, capacity markets reduce both flexibility and the resilience and antifragility that define a sustainable incentive system within a competitive electricity market. These behaviourally grounded interdependencies cannot be accurately represented within electricity market models based on neoclassical assumptions (see discussion in Section 4.1).

### Effect on Renewable Energy

Centralised capacity markets distort price signals, which undermines the profitability of various flexibility options and leads to their partial crowding-out (second-order effect). As a result, the integration of renewable energy sources is also indirectly affected by capacity markets (third-order effect). Fewer flexibility options reduce the market value of renewable energy, which in turn increases both the need for financial support and the long-term cost of support schemes.

BY IMPAIRING THE ECONOMIC CONDITIONS FOR FLEXIBILITY OPTIONS, CAPACITY MARKETS UNDERMINE THE PROFITABILITY OF RENEWABLE ENERGY AND REDUCE THE PROSPECTS OF PHASING OUT THEIR SUBSIDIES.

Central capacity markets therefore worsen the framework conditions for a cost-efficient energy transition, in which market participants can respond flexibly to the supply of renewable energy. Artificially dampened price signals increase the need for subsidies for both dispatchable capacity and renewable energy. Instead of addressing market imperfections and completing prices by internalising willingness to pay, market-based incentives are limited and distorted – leading, in turn, to an increase in externalities.

### Repercussions on Competition

The restrictions on market-based allocation caused by derating factors, market segmentation, and other regulatory provisions distort not only the technology mix but also – over the medium to long term – the competition between companies. The fragmentation of the procured volume into Y-4, Y-2, and Y-1 auctions in the Belgian capacity market reduces the level of competition in each individual auction, thereby increasing the potential for market power abuse.

One of the main reasons for the reduction in competitive intensity in capacity markets lies in the limitation of the internal market. Derating factors are also applied to cross-border capacities. While the electricity market benefits from high competitive intensity due to the internal market, cross-border competition in capacity markets is constrained by the application of derating factors. From the perspective of internal market integration, capacity markets therefore represent a step backwards toward nationally segmented markets.

By incentivising national overcapacities, the level and volatility of price signals are artificially suppressed. In addition to undermining flexibility options and renewable energy sources, this also dampens incentives for innovation. In this sense, capacity markets act as a barrier to entry for innovative technologies and new market players. As dominant market actors benefit from the capacity market, their market power in the electricity market can also increase over time.

These artificial restrictions on technological and cross-border competition are among the key reasons for the inherent market power challenges associated with capacity markets.

### Measures to Limit Market Power and Their Consequences

There are various ways in which companies can exploit their market power in capacity markets depending on the situation. For instance, they may leverage their information advantage and the volume of capacity they control to manipulate prices by withholding capacity or bidding themselves out of the market. Alternatively, they may undercut competitors by offering bids at very low prices. For regulatory authorities, it is extremely difficult to determine when a plant is genuinely unable to participate due to technical constraints or to assess the actual costs – including revenues from the electricity market – that are theoretically supposed to be reflected in capacity market bids.

As discussed earlier in Section 5.1 on selective mechanisms, the German Federal Cartel Office (Bundeskartellamt, 2023) found that one company in Germany clearly exceeds the dominance threshold, while two others are approaching it.[44] The authority also expects market concentration to continue increasing due to the decommissioning of generation units by other producers. According to the Cartel Office, import capacity and cross-border trade within the internal market are key factors in limiting market power. Since capacity markets restrict competition from foreign power plants through derating factors, the potential for market power is inevitably higher in national capacity markets than in the electricity market. As a result, it can be expected that the concentration in the electricity market will also increase over time.

TO ADDRESS THE POTENTIAL FOR MARKET POWER IN CAPACITY MARKETS, A LARGE NUMBER OF PARAMETERS MUST BE ADMINISTRATIVELY DEFINED.

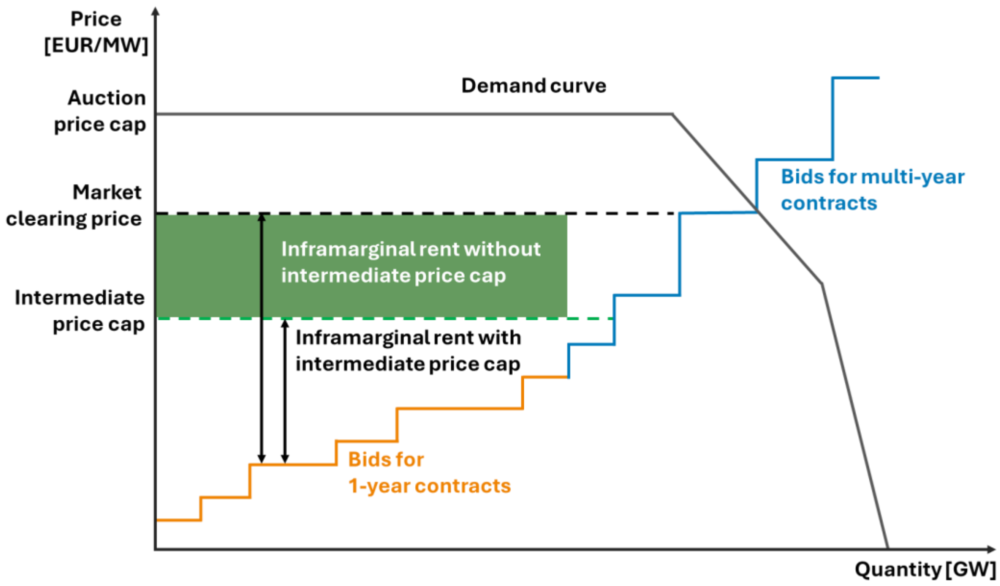
Because market power control in capacity markets is hardly feasible, regulators rely on design approaches intended to limit the potential for abuse. However, there is no ideal way to contain market power. As a result, the approaches used represent compromise solutions that typically satisfy neither regulators nor market participants. This dissatisfaction often gives rise to an ongoing demand for reforms and adjustments, which in turn leads to the inherent instability of capacity markets and to structural uncertainty.

To limit the abuse of market power, the Monopolies Commission (2023) proposes, for example, that existing plants should be required to participate in the capacity market with zero bids. While this would prevent them from directly setting prices, they could still withhold capacity, which could drive prices up. This appears particularly plausible, as power plants incur regular maintenance and retrofit costs. If they are not allowed to factor these costs into capacity market bids, it may be justifiable for them to withhold their capacity, potentially leading to higher capacity market prices and enabling new investments by those same operators.

If such a rule were combined with a bidding obligation for existing power plants, it could lead to financial risks and regulatory uncertainties, which might raise questions of property rights. In the Belgian capacity market, different price caps are applied in an attempt to mitigate this issue.

[44] The presumption threshold is merely an indicator of potential market power based on market share in specific market situations. It does not indicate whether companies actually exercise this market power.

*Figure 20: Illustration of the Price Caps in the Belgian Capacity Market*




*Source: Own illustration based on Elia (2019).*

Figure 20 shows that the demand function includes an absolute price cap. This is necessary in capacity markets to prevent excessively high prices in the event of an undersupply and the exercise of market power in the respective auction. The cap is based on the "Cost of New Entry" (CONE).[45] In addition, there is a separate price cap for existing assets submitting a bid for a single delivery period. If a bid is submitted for multiple delivery periods along with proof of investment costs, the absolute price cap applies.

This approach simulates a "cost-plus regulation"[46] based on a competitive auction. In a competitive market, compensation is based on the value provided, regardless of the age of the "tools" used to deliver that value. For comparison: the price of a taxi ride does not depend on whether a new car is used, but on whether the service is delivered. In the electricity market, the system value of a megawatt-hour does not depend on whether it is produced by an old or a new plant, whether it comes from a storage facility, or whether the market is cleared through demand reduction or shifting. It is the system value that should be remunerated to provide appropriate incentive signals and stimulate new

[45] The Cost of New Entry (CONE) is a key element in capacity markets. It estimates the investment and operating costs of a power plant and is used, among other things, to determine bid caps. The bid cap can be based either on the actual investment costs of the expected marginal technology or on the amount the marginal technology needs to earn in the capacity market, taking into account expected revenues from the electricity market. In the case of artificially induced overcapacity, the marginal plant will not generate significant revenues on the electricity market, which is why, in the long term, the bid cap should correspond to the fixed costs of the marginal technology.

[46] Under cost-plus regulation, a regulated company is allowed to recover its incurred costs plus a reasonable rate of return. A regulatory authority oversees the appropriateness of the remuneration and adjusts it as needed. In contrast, revenues in market-based industries are determined by the value created through the matching of supply and demand.

technologies and innovation when needed. The market organisation of capacity markets therefore differs significantly from the incentive logic of competitive electricity markets due to their degree of regulatory intervention.

The need for price caps in capacity markets clearly illustrates how difficult it is to create truly competitive conditions in such markets. Competition authorities are unable to determine whether high capacity bids are based on pessimistic expectations regarding future electricity market revenues, or whether they reflect an abuse of market power. Another layer of regulatory restriction arises from the prequalification requirements for multi-year contracts. Market participants must provide proof of the necessary investments in order to prequalify for longer-term capacity contracts. As a result, investment behaviour can be strategically optimised according to the market design rather than driven by the actual needs of the electricity system. For example, the timing of retrofit measures may follow a strategic rationale rather than being aligned with system adequacy requirements.

FROM THE PERSPECTIVE OF POWER PLANT OPERATORS, ADJUSTMENTS TO PRICE CAPS AND REVENUE CLAWBACK MECHANISMS REPRESENT INHERENT UNCERTAINTIES OF CAPACITY MARKETS.

Regulations in various capacity markets are continuously revised. It is therefore conceivable that, over time, additional bid caps for multi-year contracts will be introduced, calibrated to the level of prequalified investment costs. From a regulatory standpoint, it makes little sense to allow higher revenues than are necessary to cover costs. Viewed in this light, further adjustments are both desirable and foreseeable – aiming to approximate a cost-plus regime as accurately as possible. As a result, ongoing reforms that limit bids and claw back excess revenues represent an inherent uncertainty of capacity markets from the perspective of plant operators.

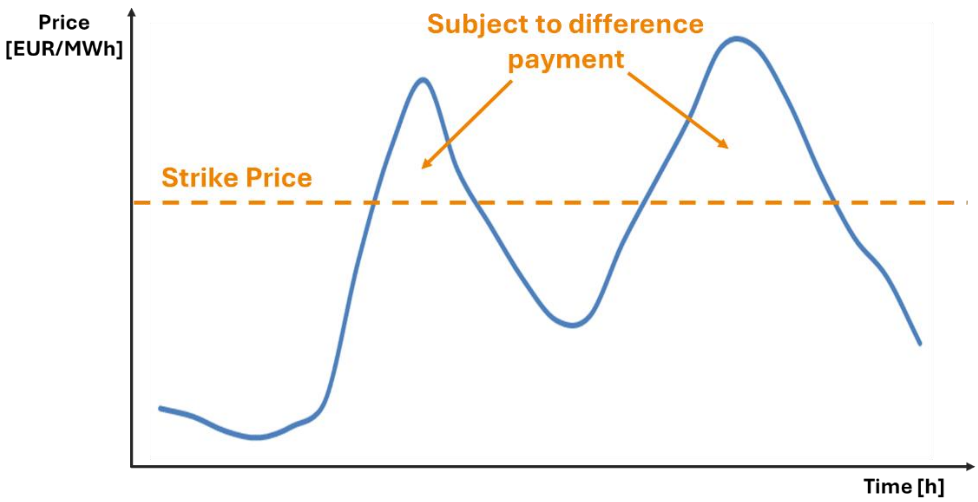
### Revenue Clawback in Capacity Markets

As previously discussed, one of the key motivations for the recent European electricity market reform was to strengthen consumer protection. However, even before the energy crisis, support schemes increasingly came under scrutiny regarding revenue clawbacks in order to prevent overcompensation. This is because the threshold for overcompensation is lower than the threshold for what is often referred to as "excess profits".

For this reason, Contracts for Difference (CfDs) for the support of renewable energy have long been under discussion. This perspective has also become embedded in the state aid approvals of capacity markets. For instance, the Belgian capacity market was approved in part due to the inclusion of revenue clawback mechanisms, which also serve to mitigate market power. In the Belgian capacity market, revenue clawback is organised through Reliability Options.[47] This is yet another indication that central capacity markets are effectively treated as subsidy schemes, rather than as components of a sustainable market design.

If a bid in the capacity market is awarded, the power plant operator grants an option to the regulator in return for the capacity payment. A Reliability Option is essentially a price cap agreement between a generator and the holder of the option – in this case, the central entity acting as the single buyer. When the electricity market price exceeds the agreed strike price, the generator pays the difference between the market price and the strike price to the option holder. This mechanism ensures that any profits above the strike price are clawed back. Figure 21 illustrates how these options work in practice.

*Figure 21: How a Reliability Option Works*




*Source: Own illustration.*

The options are likely necessary for the functioning of capacity markets, both to limit the exercise of market power and to ensure compliance with state aid approval requirements. They eliminate incentives for power plant operators to drive up electricity prices. At the same time, they encourage generators to

[47] There are occasional claims that municipal utilities are not permitted to engage in options trading. If this restriction applied, they would be excluded from participating in central capacity markets, since reliability options are usually an integral element of these mechanisms.

produce electricity during scarcity situations, since the repayment obligation applies even if a plant does not feed electricity into the grid.[48]

However, the clawback of revenues means that power plants will increasingly rely on income from the capacity market, as these clawbacks are factored into their bidding strategies. From the state's perspective, there is also an incentive to set the strike price as low as possible, in order to redistribute the clawed-back funds.[49]

Although support mechanisms are ideally designed to be temporary – allowing technologies to become self-sustaining – revenue clawbacks create a path dependency. This makes a return to a market-based system highly unlikely.

### Expected "Adjustments" to Revenue Clawback

Revenue clawbacks on the electricity market via Reliability Options offer a way to limit overcompensation resulting from unexpectedly high market revenues. However, there is currently no equivalent mechanism to claw back excessive capacity payments. The price caps in capacity markets are merely attempts to prevent overcompensation ex-ante.

Capacity market bids are composed of fixed costs incurred before and during the delivery period, minus the expected revenues from the electricity market during that period. Since bids must be submitted well ahead of the delivery period (Y-4, Y-2 or Y-1 in Belgium), they are based on revenue forecasts that are difficult for regulators to verify. If a bidder assumes low power market prices four years ahead – thereby justifying higher capacity market bids – regulators have limited means to challenge or restrict this assumption.

In the recent revision of the EU Electricity Market Regulation (2024), a new provision on transparency obligations was added (Art. 7.2f), which sparked discussion under the term "unit-based bidding."[50] There were concerns that this rule might implicitly signal a shift away from portfolio bidding towards asset-specific bids in power trading.[51] Such a move would have significant

[48] However, for insurance and financial reasons, a number of exceptions due to 'force majeure' are inevitably required.

[49] In France, for example, there are considerations to finance the fixed costs of nuclear power plants through Contracts for Difference (CfDs) and to use the clawback revenues to reduce the cost burden on electricity consumers.

[50] EU Electricity Market Directive (2024) Article 7(2)(f): "be transparent and, where applicable, provide information by generation units while at the same time protecting the confidentiality of commercially sensitive information and ensuring trading occurs in an anonymous manner;"

[51] The ability to submit portfolio bids was, for example, a key prerequisite in Germany for increasing flexibility and, in turn, competition in balancing and electricity markets. This greater flexibility and competition led to lower prices and improved supply quality. In addition, it provided the basis for better integration of renewable energies at lower cost, which in turn contributed to a reduction in RES support expenditures. The openness to innovation inherent in portfolio bidding is therefore a foundation for low total system costs.

implications for the marketing of generation portfolios and virtual power plants, as it could limit the flexibility to aggregate and optimise across different assets.

The reform of the regulation was primarily driven by the energy crisis, which, among other things, exposed difficulties in clawing back generator revenues during periods of high electricity prices and redistributing them in line with consumer protection objectives.

From the perspective of cost-efficient regulation of capacity markets, it would indeed be conceivable to use this "unit-based bidding" regime as a means of ex-post calculating the contribution margins of individual units (or blocks of units). While an ex-ante assessment of capacity market bids based on projected electricity market revenues is difficult to verify, unit-specific bidding would allow those revenues to be approximated with reasonable accuracy after the fact. This data could then be used as the basis for ex-post revenue clawback mechanisms in the capacity market. In this way, the approach would represent the capacity market equivalent of revenue clawbacks in the electricity market via Reliability Options.

THE ADJUSTMENT WOULD REPRESENT ANOTHER STEP TOWARD A COST-PLUS REGULATION FOR SUBSIDISED UNITS.

Given the cost burden of the energy transition on businesses and households, the clawback of revenues from subsidised assets appears to be a politically attractive means of redistributing excess earnings. However, such an adjustment would merely constitute another step towards a cost-plus regulatory regime for subsidised assets, further emphasising the regulatory uncertainty faced by power plant operators under capacity market frameworks.

### The Challenges of Centralised Capacity Planning

Central capacity markets are characterised by a wide range of parameters that must be defined by a central authority. We have already discussed derating factors and restrictions on bids and prices, both of which significantly limit the scope for market-based incentives. However, the most fundamental challenge – and the one that poses the greatest risk of long-term distortions and rising system costs – is the determination of the demand volume to be auctioned.

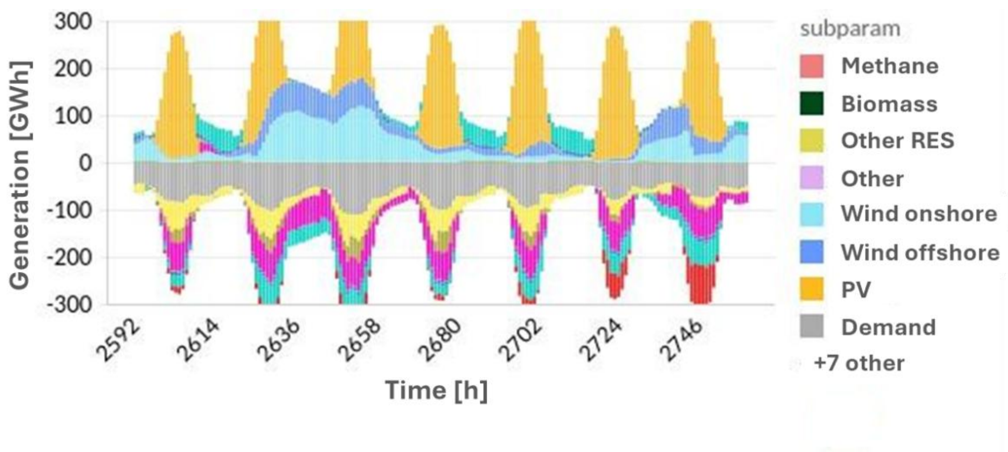
In static systems, where demand and the technological composition of the system do not change significantly over time, historical peak demand can serve as an indicator for future peak load expectations. The amount of capacity to be procured can then be determined based on this expected peak load plus a security margin.

However, this approach is not suitable for dynamic systems, particularly those undergoing large-scale decarbonisation through the electrification of other sectors. This applies especially when the system is undergoing a fundamental transformation involving a structural change in the generation fleet.

To decarbonise the transport and heating sectors, it will be necessary to expand renewable energy generation far beyond what is required to decarbonise the traditional electricity sector alone. Fortunately, new consumer technologies offer significant flexibility potential, allowing electricity demand to be shifted – often without any loss of comfort – to times when renewable electricity generation is high. Apart from periods of dark doldrums (Dunkelflauten), this shift is largely feasible and desirable. In particular, low electricity prices during periods of high renewable output provide a strong incentive for flexible consumption.

This concentration of demand during high renewable output periods is expected to result in significantly higher peak loads than those typically observed in traditional power systems. However, these new peaks are not relevant for system adequacy planning, since they occur in periods of abundant renewable energy availability and low electricity prices. Figure 22 illustrates such a situation in spring 2045, based on the long-term scenarios published by the BMWK (2024).

*Figure 22: Dispatch in 2045 Based on the Long-Term Scenario T24-Electricity*




*Source: Langristszenarien (BMWK, 2024).*

In Figure 22, it is evident that cumulative generation clearly exceeds 300 GW, and that cumulative demand (adjusted for net exports and shown in the negative range) is of a similar magnitude.

In periods with low renewable availability, prices are expectedly significantly higher, which incentivises a lower level of electricity consumption. These periods are therefore characterised by significantly lower demand than the absolute peak load. This gives rise to the question of what capacity demand should be based on in the context of a capacity market.

This question ultimately determines the role that capacity markets are intended to play in the organisation of the electricity market. If the aim is to ensure lower electricity prices than those in a competitive electricity market – a politically attractive objective – then capacity demand would have to be based on theoretical peak loads. These peak loads occur when, in winter, a large share of the population is heating their homes, charging electric vehicles, and industry is simultaneously operating at full capacity due to favourable economic conditions. Figure 22, in combination with the installed capacities of decentralised consumption technologies shown in Figure 5, suggests that the required generation fleet would need to be several times larger than today's. For various reasons, this scenario appears unrealistic and unattractive.

Nevertheless, determining capacity demand is far from straightforward. The issue evolves over time (and not through a comparison of equilibrium states, as electricity market models tend to imply), which means that a continuous increase in capacity demand is likely. Relying on electricity market models ignores this dynamic perspective, as they calculate equilibria. The interactions that arise between price signals on the one hand and political and economic considerations on the other, especially in periods of transformation, cannot be adequately captured by these models.

In Section 4.5, we discussed how a market equilibrium can emerge based on the willingness to pay of flexible consumers. As the system evolves, efforts to reach equilibrium repeatedly result in high-price situations that incentivise demand reductions. In such a system, electricity demand – and thus the relevant peak load – depends on the price. When price levels rise, investing in new power plants becomes attractive. In this context, price signals reflect consumers' willingness to pay, allowing them to communicate the need for new generation capacity through their price-elastic behaviour.

However, the incentive structure in a system with capacity markets works fundamentally differently. To illustrate the challenges arising from the need to determine capacity demand administratively, we propose a thought experiment: we construct a hypothetical scenario with a capacity market and the corresponding planning processes.

### Thought Experiment: Planning Capacity Demand

Over the coming years, more and more decentralised consumption technologies will be added to the system. This will inevitably lead to situations with high electricity prices, prompting consumers to reduce their demand. As preparations begin for the next capacity auction, a central authority must determine – typically four years ahead of the delivery year – how much capacity should be procured. The variation in residual peak loads shown in Figure 12 illustrates the challenge facing decision-makers. A key question arises: should power plants be procured even if they are only expected to produce electricity once every ten years – or potentially never? It is unlikely that such a decision could be made without political influence and debate (e.g. during scenario development). The logic and incentive structure of capacity markets make political decision-makers, who operate with incomplete information, vulnerable to misguided incentives and lobbying (rent seeking). The disconnection between information, risk, and incentives results in misallocations – the costs of which must ultimately be borne by society.

THE DECOUPLING OF INFORMATION, RISK, AND INCENTIVES IN ECONOMIC DECISION-MAKING LEADS TO HIGHER COSTS FOR SOCIETY.

If scarcity situations with high prices have already been observed on the electricity market, system planners – looking four years ahead – will logically assume that demand will continue to increase due to the growing number of decentralised consumption technologies. From a planning perspective, the logical consequence is to procure more capacity. Since the system planners also aim to include a security margin, this overcapacity will tend to depress electricity prices. However, these prices do not reflect the consumers' willingness to pay (or their opportunity costs). This distortion of (incomplete) prices, caused by artificially incentivised overcapacity, inevitably leads to externalities.[52]

If generation capacity is expanded too slowly, scarcity situations are still likely to arise at some point.[53] These scarcity events – partly due to limited flexibility – are accompanied by high prices. However, in this system logic, unlike in a competitive electricity market, high prices are not seen as an incentive mechanism but as a "problem" that must be addressed by adding more capacity.

[52] Externalities can take many forms. In this context, they may include, among other things, insufficient investment in flexibility options and the reinforcement of inflexible consumption habits that place unnecessary strain on the system.

[53] For the specific interactions in market dynamics, however, it is crucial whether hydrogen power plants receive an $H_2$-CfD or whether they have to factor in their full marginal costs (see discussion in Section 5.1).

One of the arguments sometimes made against competitive electricity markets is that policymakers are unwilling to accept high electricity prices. On the other hand, planned overcapacity results in low prices, which make decentralised consumption technologies more attractive. This, in turn, leads to new peak demand events, which once again increase capacity demand. The absence of market feedback and the lack of incentive for a price-driven market equilibrium creates a slippery slope[54] of ever-increasing generation capacity.

THE ABSENCE OF MARKET FEEDBACK AND A FUNCTIONING MARKET EQUILIBRIUM LEADS TO A SLIPPERY SLOPE OF INCREASING GENERATION CAPACITY.

When power market models are used for capacity planning, they inevitably assume a competitive electricity market that utilises all available flexibilities to achieve an efficient equilibrium. However, in reality, this efficient utilisation is based on the incentive effects of price signals. These price signals, in turn, are likely to trigger a politically motivated administrative expansion of generation capacity, which prevents a true market equilibrium. Instead, generation capacity is continuously expanded through administrative procurement.

Over time, however, it becomes evident that the slippery slope of continuous capacity expansion is not a sustainable strategy. At some point, someone would need to advocate for refraining from further capacity additions and instead accept the scarcity situation – expecting flexible consumers to reduce their demand. However, this perspective is not consistent with the incentive structure of capacity markets and is politically unpopular.[55]

If the main instrument for determining capacity demand were the willingness to pay of flexible consumers, there would be no need for a capacity market. The amount of controllable capacity would be determined by the willingness to pay of price-elastic consumers. In contrast, the central approach of a capacity market is that a central authority determines the required capacity. However, it is not clear how this administrative determination could be designed in a system that is, at times, characterised by peak loads of several hundred gigawatts. In the critical transformation phase of the 2030s, new consumer technologies with gigawatt-scale capacities are expected to be connected to the grid every year –

[54] The slippery slope effect describes a process in which an initial, often subtle step triggers a sequence of further steps that ultimately result in significant negative consequences. Since each subsequent step on the slope appears necessary and unavoidable, the only way to avoid the adverse outcome is to refrain from taking the first step. In this regard, the concept of the slippery slope resembles the so-called 'oil spot theory'. However, while the slippery slope refers to an inevitable chain of causal consequences, the oil spot theory typically describes the diffuse spread of influence.

[55] The security of supply scenarios and the Grid Development Plan (NEP) are essentially based on a market equilibrium enabled by flexible consumers. However, the decisive factor is not the technical system itself, but the incentives that drive the development towards such a system – namely, price signals that encourage behavioural change, which are often perceived as 'uncomfortable' from a political perspective.

capacities that would need to be factored into the capacity demand in the auction with a four-year lead time.

The likelihood of disproportionately high system costs appears probable when taking into account the political-economic incentives for continuous capacity expansion that unfold over time. A return to a competitive electricity market design – one that incentivises market equilibrium through increasing flexibility – seems highly unlikely due to the inherent path dependencies of capacity markets. As previously discussed, revenue-capping mechanisms in capacity markets make it difficult for power plant operators to imagine financing significant overcapacities via the electricity market alone. The discontinuation of capacity payments would result in extensive plant closures and trigger a societal debate on security of supply – one that would be politically difficult to sustain.

This thought experiment illustrates the challenge of administratively determining capacity needs in a dynamic electricity system. For power plant operators, the uncertainty about long-term capacity demand, combined with the unsustainable need for public financing, results in incalculable uncertainty driven by difficult-to-predict regulatory adjustments.

### Political-Economic Framework Conditions

In a power system with capacity markets, political decision-makers and market actors face different incentives compared to a system that is organised according to market-based principles and encourages market equilibrium. Moreover, information asymmetries exist between economic actors and political decision-makers, which, given the multitude of parameters that must be defined, can inevitably lead to political influence and rent seeking.

The distribution of information and incentives between political and economic decision-makers in a system with capacity markets results in a shift of risks. Those actors who would be capable of managing these risks – and for whom risk exposure would create valuable incentive signals to avoid unnecessary additional costs – are relieved of that burden. Instead, society, which is not in a position to manage these risks, bears the additional costs (moral hazard). This redistribution inevitably leads to externalities in the form of welfare losses.

The financing of capacity markets is organised either through the federal budget, dedicated funding schemes, or levies. As a result, price signals are inevitably distorted. The main additional costs arise from the misaligned incentives of these distorted (incomplete) price signals, which lead to the crowding-out of flexibility options and innovations, while building up thermal overcapacity. It is in the nature of path dependencies – particularly those triggered by subsidy schemes – that their effects accumulate over time. By the time the additional costs are recognised as a burden on society, the system has typically reached a point where, due to the embedded path dependency of continued subsidies, a change of system appears unthinkable.

SUBSIDY-INDUCED PATH DEPENDENCIES ACCUMULATE OVER TIME. BY THE TIME THE COSTS BECOME A SOCIETAL BURDEN, A SYSTEM CHANGE IS TYPICALLY UNTHINKABLE.

It can also be expected that political debate will arise over who should bear the direct and indirect additional costs. As seen in the ongoing discussions around industrial electricity prices and the design of individual grid charges (Section 19(2) of the StromNEV), combined with concerns about Germany's competitiveness as an industrial location, it is regularly apparent that imposing additional costs on industry is politically difficult to justify. As such, it is conceivable that special arrangements could be introduced to relieve industry of capacity payments. These costs would then have to be borne by other consumer groups, thereby further increasing their financial burden.

The challenge of centralised capacity markets lies in the need to centrally determine key design parameters, such as derating factors, procurement and product characteristics, and the total capacity to be contracted. By their nature, all of these design choices are vulnerable to political influence. These decisions inevitably rely on assumptions about the future, and the administrative determination of such framework conditions leads to the exclusion of incentives and, by extension, of viable solutions.

In summary: planning remains planning. Even when complex technical tools are used, it is still centrally defined assumptions that determine future solution spaces. This inevitably results in misallocations that increase overall system costs.

The attempt to calibrate the multitude of regulatory levers in a balanced way is essentially an effort to achieve a local optimum. Capacity markets represent an attempt to solve a complex task with a

THE ATTEMPT TO LIMIT MARKET POWER THROUGH BID CAPS AND REVENUE CLAWBACK INSTRUMENTS RESULTS IN REGULATORY MICROMANAGEMENT.

complicated mechanism. The price for this is the displacement of a wide range of essential allocation functions. The effort to limit market power by simulating a Cost-Plus regulation through bid caps and clawback mechanisms inevitably results in regulatory micromanagement. This, in turn, increases both the motivation for political influence and the susceptibility to distorted political-economic incentives. Overall, the attempt to centrally micro-manage a complex system has, as experience shows, a lasting negative impact on societal welfare.

## 5.4 DECENTRALISED CAPACITY MARKETS

Decentralised capacity markets differ from centralised capacity markets in that they make use of decentralised, distributed information and rely more heavily on incentive-based allocation of technologies and volumes by market participants. In this sense, decentralised capacity markets are more aligned with the characteristics of a market design, whereas centralised capacity markets resemble more closely a subsidy-based design.

A wide range of design options is fundamentally possible for decentralised capacity markets, which differ, among other things, in the depth of regulatory requirements and the level of monitoring needed.[56] The most concrete design proposal in Germany for a decentralised capacity market was presented by BDEW (2014) under the name “Dezentraler Leistungsmarkt” (DLM – Decentralised Capacity Market), which incentivises secured capacity through so-called supply security certificates (Versorgungssicherheitsnachweise, VSN). We therefore base the following discussion largely on these design proposals. Where appropriate, we point out the differences compared to centralised capacity markets and highlight possible complementary design options for decentralised capacity mechanisms.

BDEW (2014, p. 6) describes the role of the DLM as follows: “A key characteristic of the decentralised capacity market is that no state regulator centrally determines the amount of secured generation capacity to be provided, nor are the associated costs distributed independently of the cost causer. Instead, the total volume of required capacity certificates (VSN) is defined by the actual demand of electricity consumers and financed according to the polluter-pays principle. Moreover, the DLM allows significant flexibility for the inclusion of demand-side measures, which can reduce electricity demand during scarcity

[56] In France, for example, a less regulated, decentralised capacity market was initially developed. However, in the course of the political design process and the state aid discussions with the European Commission, additional central requirements were introduced.

periods, and is thus advantageous in tapping into DSM potential." The following overview outlines the key features of decentralised capacity markets.

- SCOPE/QUANTITY: Suppliers (or balancing group managers) procure the future capacity needs of their customers, taking into account their flexibility and their preferences for secured capacity. In this way, the entire market's demand is addressed – similarly to central capacity markets. However, consumers can determine their own capacity needs and respond flexibly in times of scarcity.
- TECHNOLOGICAL SELECTION: Various technologies can be used to meet capacity demand. Unlike central capacity markets, decentralised mechanisms can take advantage of dispersed information about consumers' flexibility potential, which allows them to incorporate demand-side contributions more effectively. As a result, decentralised capacity markets can provide stronger incentives for flexibility.
- PROCUREMENT: Providers of secured capacity can issue standardised capacity certificates, referred to by BDEW (2014) as Versorgungssicherheitsnachweise (VSN – supply security certificates). These certificates function similarly to reliability options in central capacity markets.[57] VSNs are tradable, either bilaterally or on organised platforms such as energy exchanges. Balancing group managers can meet their secured capacity requirements through VSNs – either by operating their own generation units or by leveraging the flexibility potential of their consumers, in which case fewer VSNs must be procured.
- REMUNERATION: The price for capacity certificates is determined on the market through supply and demand, taking all available technologies into account. "Regulatory intervention in the allocation mechanism is not required" (BDEW, 2014, p. 7).

In the following, we discuss selected features of decentralised capacity markets to illustrate their functioning – partially in contrast to centralised capacity markets.

### Rules and Incentive Mechanism of the Decentralised Capacity Market

For power plant operators, selling VSN is voluntary. Any market participant can offer a VSN. There are no quantity limits or prequalification requirements for individual assets. Instead, penalties are imposed if the guaranteed capacity is

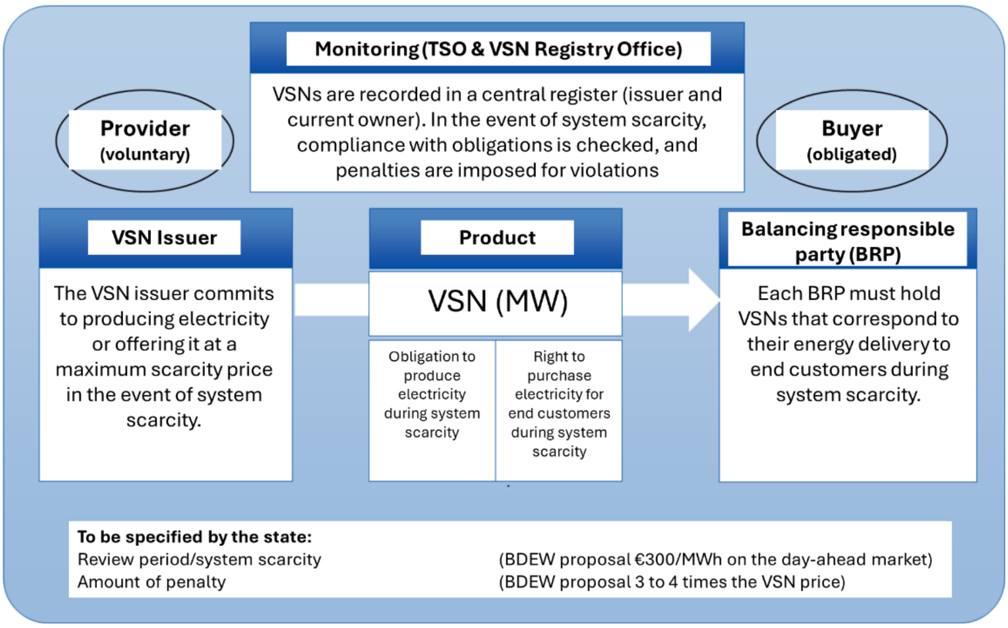
[57] As already noted in the discussion on central capacity markets, it is occasionally argued that municipal utilities are not permitted to trade in option products. If that were the case, they would also be excluded from a decentralised capacity market, as reliability standard contracts (VSN) essentially constitute option products.

not provided. To ensure that the promised VSN quantity is reliably available – especially in the event of plant outages – market participants must take appropriate measures, meaning that not all power plants will offer VSNs directly; some will instead take on a hedging role to back up others.

By their nature, VSNs are comparable to reliability options in central capacity markets. However, in central markets, participation is tied to a complex prequalification process. For multi-year delivery periods, participants must even provide financial documentation. In contrast, BDEW (2014, p. 10) highlights the financial incentive mechanism: "Availability during scarcity periods is ensured through the penalty system." At the same time, VSN issuers are obliged to deliver electricity during scarcity periods.

Trading in VSNs is open to all market participants: "In the forward market for VSNs, it is to be expected that traders will also participate as buyers or sellers. Such transactions will occur as soon as different market expectations regarding the future price development of VSNs emerge. This kind of trading is to be viewed positively, as it increases liquidity and thus enhances the relevance of the VSN price signal. As a result, it improves the efficiency of market participants' decisions. Furthermore, forward trading allows revenues from and costs of providing firm capacity to be hedged over the medium term, thereby increasing planning certainty. Buyers of VSNs can continuously adjust their demand for VSNs in line with their customer portfolio" (BDEW, 2014, p. 11). The following figure illustrates the roles within the decentralised capacity market.

*Figure 23: Overview of Rights, Duties and Tasks in the VSN System*




*Quelle: BDEW (2014).*

As shown in Figure 23, the role of the state or the regulatory authority essentially consists of defining two key elements:

- PENALTY PAYMENT: The penalty should be a multiple of the VSN price, as the incentive for VSN procurement depends on the expected value of the penalty (based on an optimisation calculus). This ensures that the level of VSN procurement is independent of the VSN price. Otherwise, at high prices, the penalty could become relatively cheaper than purchasing a VSN.
- TRIGGER POINT FOR VERIFICATION: A transparent indicator of scarcity can be a high day-ahead (DA) price (around EUR 300/MWh or roughly 20% higher than the short-run marginal costs of the most expensive power plant). If this threshold is met, the amount of VSNs held is compared with the load of the balancing group manager. At the same time, it is verified whether VSN providers have made the promised capacity available, are feeding in power, or have submitted a bid to the power exchange. "All VSN providers are obligated to produce electricity in the corresponding amount when the scarcity price is reached" (BDEW, 2014, p. 13).

The price threshold at which verification and the obligation to feed in apply corresponds to the function of the strike price in the reliability options used in the Belgian capacity market. A central authority is also required to verify whether all market participants are fulfilling their contractual obligations.

BDEW (2014, p. 8) assesses the division of responsibilities between market actors and government regulation as follows: "BDEW deliberately advocates for a market that minimises regulatory interventions and central planning elements. It therefore rejects centralised control of volumes by the state or by a state-controlled body. Experience in other electricity markets has shown that central volume control is highly demanding and has led to cost-driving inefficiencies, such as the build-up of overcapacity and a rigid demand that fails to respond to current generation conditions. A central authority is inferior to market coordination when it comes to assessing the future development of demand and supply of firm capacity – that is, in anticipating the behaviour of market participants. Nevertheless, the definition of framework parameters (e.g. the level of penalties) sets key regulatory conditions that are critical for the market's functionality and efficiency."

In a decentralised capacity market, the responsibility for substitute procurement in the event of a plant outage lies with the VSN issuer. The security margin for ensuring supply security is therefore incentivised by the VSN providers based on the penalty system: "This means that VSN issuers must guarantee 100% availability during system scarcity. To do so, they must hold reserves to cover technical outages and scheduled maintenance – either through their own assets or via contracts with third-party plants. In the case of a plant portfolio, it is not the availability of the individual plant that matters, but the availability of the VSN issuer's overall portfolio" (BDEW, 2014, p. 20). The hedging transactions between VSN providers are essentially based on options products. However, it is nearly impossible to prove whether withheld generation capacity is part of legitimate hedging strategies or an indication of market power abuse aimed at driving up VSN prices.

Buyers of VSN must anticipate their peak load at times of system scarcity and provide a corresponding volume of VSN. The penalty for failing to cover the required VSN is identical to the penalty imposed on providers for non-delivery. Information from the balance groups managed by the TSOs can be used to verify compliance on both the supply and demand sides.

### Technological Openness and Investment Incentives

For plant operators, it makes no difference whether they use existing or new assets. What matters is the ability to inject electricity during scarcity periods. In this neutrality, decentralised capacity markets differ, for example, from the centralised approach of the Belgian capacity market, which applies different price caps for existing, retrofit and new assets.

The incentives for capacity provision – and, if necessary, for new investment – arise from the design of the penalties: "An under-procurement of VSNs is significantly more expensive than a current electricity balancing group deviation. Assuming a VSN price of €30,000/MW and a penalty multiple of 4, this results in a cost of €120,000/MW per hour for a capacity balancing deviation. This means that the incentives to ensure security of supply come earlier and are around eight times stronger than they are today" (BDEW, 2014, p. 26). These incentives also affect demand-side flexibility, since flexible consumers must weigh up whether they want to procure a VSN or reduce or shift their demand at the time of verification.

Regarding investment risks, BDEW (2014, p. 30) refers to standard market-based incentives: "The investor is exposed to market risks, as in any other market. However, they can assume that there will be demand for their product – 'firm capacity' – over the coming decades. The risk that others may be able to offer the product 'firm capacity' more cheaply (e.g. due to technological progress or better cost management) is a key feature of any competitive market and leads to cost-efficient outcomes." This handling of market-based risk incentives illustrates that the Decentralised Capacity Market corresponds to a market design. In contrast, the shielding of risks through 15-year contracts in the Belgian central capacity market corresponds more closely to a subsidy scheme.

BDEW (2014, p. 8) describes the technological openness of the decentralised model, contrasting it with centralised capacity markets as follows: "Due to the limited number of regulatory specifications in the DLM, it is very flexible and open to innovation. This allows the DLM to integrate new technologies more quickly and easily than centralised capacity markets, which typically include more restrictive requirements (such as those planned in the UK or applied in the PJM market area)."

### Political-Economic Temptation and Pitfalls of Decentralised Capacity Markets

From a political-economic perspective and in terms of efficient price incentives, it is advantageous that security of supply does not have to be financed through the federal budget, dedicated funding schemes, or levies. Security of supply becomes part of the price signal. BDEW (2014, p. 27): "The costs of the capacity certificates (VSN) are priced into final consumer products via competition. This reveals end consumers' willingness to pay for security of supply and provides a strong incentive to unlock flexibility potential on the demand side."

As the detailed design proposed by BDEW (2014) shows, decentralised capacity markets hold considerable potential to ensure security of supply at low cost while also incentivising the flexibility that is essential for the energy transition. However, the concrete design of the individual elements can vary in detail. The distinction between centralised and decentralised approaches often involves grey areas along a spectrum. Political-economic incentives therefore tend to encourage a gradual shift towards more centralised specifications over time.

DECENTRALISED CAPACITY MARKETS TEND TO CONVERGE TOWARDS CENTRALISED CAPACITY MARKETS OVER TIME THROUGH POLITICAL ADJUSTMENTS.

In Connect (2014), we already pointed out that additional design elements could be introduced by the state to increase the politically perceived effectiveness of the decentralised approach. As a result, the decentralised model could gradually converge towards central capacity markets and, over time, be fully replaced by a centralised approach.

It would be a logical next step to introduce, for example, initial prequalification criteria and more complex prequalification procedures for VSN providers, as seen in the French decentralised model. After all, ensuring security of supply can always serve as a compelling justification for further interventions – especially when market outcomes do not align with the preferences of specific stakeholders. This would gradually shift the approach closer to a central capacity market. The information required for prequalification could then be used by central authorities to design clawback mechanisms as soon as prices begin to rise.

On the demand side, additional requirements could be imposed on hedging and procurement behaviour to ensure that there is sufficient demand. Moreover, prequalification criteria could be introduced for various flexibility options to ensure that any reduced demand for VSNs is indeed matched by actual flexibility potential.

However, such adjustments would increase the effort and transaction costs for all market participants, thereby raising short-term costs and hindering innovation in the long term. Decentralised capacity markets therefore represent a slippery slope towards centralised capacity markets. For example, the French capacity market was initially designed as a decentralised model. After several rounds of adjustments, a transition to a central capacity market was eventually decided.

## 5.5 HYBRID MODEL: DECENTRALISED AND CENTRALISED

The discussions on decentralised and central capacity mechanisms have shown that each model comes with specific advantages and disadvantages. For this reason, the Monopolies Commission presented a proposal for a hybrid capacity market model that combines both approaches in its sector report on the electricity market (Monopolkommission, 2023). The hope behind this proposal is that a hybrid design could harness the respective strengths of each model while avoiding their respective drawbacks.

The report notes that within a central capacity market, "due to political-economic risk aversion, an excessively high level of secured capacity may be mandated." It adds: "Although the fundamentally more market-based decentralised capacity market model cannot solve this problem entirely, it does offer a considerable advantage in that demand-side actors are included and thereby incentivised to save" (Monopolkommission, 2023, p. 76).

Since the proposed model incorporates elements of both decentralised and central capacity markets, the following discussion focuses on its distinctive features and does not repeat the characteristics already covered in detail:

- SCOPE/QUANTITY: The Monopolies Commission's proposal constitutes a comprehensive mechanism designed to include all capacities to ensure security of supply during peak demand. The approach starts with decentralised procurement, and in the event of an undersupply, a central authority has the option to procure additional volumes via a central mechanism.
- TECHNOLOGICAL SELECTION: The combination of decentralised and central elements is intended to enable broad technological participation. The decentralised element includes flexible consumers who can secure their preferred level of supply security and are not required to present certificates for the flexible share of their demand. The central element is intended to support the retention of existing power plants and, where necessary, incentivise new investments.
- PROCUREMENT: Providers of secured capacity from both existing and new assets can prequalify and offer capacity certificates on the decentralised market up to four years ahead of the delivery period. The regulator then has the option to tender additional capacity on the central capacity market if an undersupply is anticipated.
- REMUNERATION: On the decentralised market, prices are determined by supply and demand, with the expectation of potential additional procurement via the central capacity market already priced in. Providers of secured capacity will not accept a price on the decentralised market that is lower than the anticipated price on the central market.

Compared to the central capacity market, the Monopolies Commission (2023, p. 78) places strong emphasis on the use of decentralised knowledge and the preferences of consumers: "For determining their actual needs in scarcity situations, the market-based structure of the decentralised capacity mechanism is particularly well suited. Consumers themselves are best positioned to assess the extent to which they can flexibly respond to scarcity situations, for example through demand reduction."

### Market Design and Determination of Capacity Demand

With regard to the demand for secured capacity, the Monopolies Commission assumes that while consumers are capable of estimating their expected demand, they tend to underestimate the probability of exceptional situations (e.g. extreme cold). As a result, they would request the statistically appropriate average quantity of secured capacity but not the amount required in extreme cases: "The median corresponds precisely to the capacity volume that is equally likely to be sufficient or insufficient to fully meet demand. The decentralised approach is therefore suitable for determining the baseline demand for flexible capacity from the market itself" (Monopolies Commission, 2023, p. 78).

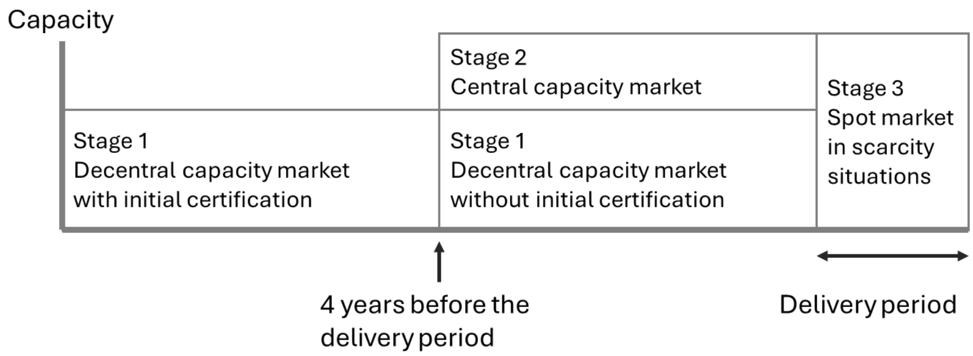
This knowledge of baseline demand should then enable the regulator to more accurately estimate total capacity needs: "If the baseline or median demand is known, this information provides a valuable indicator of the approximate size of the optimal total capacity volume." [...] "If at least the baseline demand is known, the potentially significant estimation errors [by the regulator] affect only the additional need. This volume is relatively small, meaning the scope for error is likewise smaller. The additional demand should be procured by the regulator. The established central capacity market model is suited to this purpose."

The hybrid approach comprises three stages:

- A decentralised capacity market, in which capacity assets can be prequalified up to four years ahead of the delivery period.
- A central capacity market, through which the regulator can procure any additional capacities it deems necessary.
- The delivery period, during which the energy-only market utilises the procured capacities and determines actual demand.

Figure 24 illustrates the relationship between the three stages of the hybrid approach.

*Figure 24: Timing of the Hybrid Capacity Market Model*




*Source: Own illustration according to Monopolkommission (2023).*

Ending the certification process four years before the delivery period is an example of the compromises that may be necessary when designing capacity markets. A central auction held four years ahead of delivery (Y-4) cannot represent the final opportunity for new assets to enter the market. Some technologies have significantly shorter construction lead times. Denying them market access or participation in the comprehensive capacity market would have a strongly distortive effect. It is therefore likely that further market segmentation – such as Y-2 and Y-1 auctions, as seen in the Belgian capacity market – would be required in order to avoid entry barriers.

### Market Differentiation and Addressing Market Power

Unlike the Belgian capacity market, the proposal does not differentiate between existing and new assets in terms of remuneration. As the Monopolies Commission (2023, p. 91) argues: "Treating existing and new assets equally helps determine whether new construction is economically viable." This approach places a stronger emphasis on market-based incentives than the highly regulated practical examples. However, it remains questionable whether these principles can withstand political debate during concrete implementation and the associated cost allocation.

A trade-off emerges in the handling of market power. Measures to restrict market power are not economically optimal but may be necessary to enable a competitive market environment. As the Monopolies Commission (2023, p. 92) explains: "In the proposed multi-stage capacity mechanism, this would mean that operators of existing assets could be required either to certify their assets in Stage 1, to submit them in Stage 2 for the state auction, or to decommission them. If they opt for a bid in Stage 2, zero-bids could additionally be mandated."

However, zero bids do not mean that existing assets owned by market-dominant companies would go uncompensated – they would simply not be allowed to submit price-setting bids. They would still receive the capacity price awarded to all other market participants.

### Price Hedging and Revenue Clawback

On the question of whether capacity certificates should be designed as reliability options[58] for the purposes of price hedging and revenue clawback, the Monopolies Commission (2023, p. 93) takes a more open stance than other approaches: "Overall, the Monopolies Commission does not consider it essential that reliability options be mandated in the capacity market. It is unclear whether the advantages outweigh the disadvantages. As part of

[58] See explanation in Section 5.3.

contractual competition, it could be left to market participants to decide whether they wish to enter into a reliability option. The Monopolies Commission currently sees no need for a strict regulatory link."

Allowing market participants to voluntarily choose reliability options provides a promising way to accommodate individual preferences. However, it is likely that some form of revenue clawback will be required to ensure that capacity markets are approvable by the European Commission. Thus, it can be expected that this voluntariness will give way to an obligation in the course of implementation, in order to avoid overcompensation and to secure approval.

### Political-Economic Slippery Slope

The decentralised and central capacity markets proposed by the Monopolies Commission are intended to jointly incentivise a sufficient amount of capacity. However, to increase the incentive effect of the central element, it is likely that features will be introduced to enhance its attractiveness. For example, longer remuneration periods could be offered. This would represent a typical distorted incentive, where holding back investments in the decentralised capacity market is rewarded by the prospect of more favourable conditions in the central capacity market.

Regardless of the specific elements used to make the central capacity market more attractive, the incentive effect of the decentralised element is weakened in comparison. As a result, the decentralised element may ultimately only be used for certain flexibility options and innovative technologies. However, their certification would have to be completed four years before the delivery period. This contradicts the very nature of flexibility options and innovations, which typically have shorter lead times and steeper learning curves. Further segmentation into Y-2 and Y-1 auctions therefore seems likely.

As discussed in the context of the decentralised capacity market (BDEW, 2014), successive adjustments towards a centralised capacity market appear probable over time – eventually leading to a complete transition, as currently seen in France. The proposal by the Monopolies Commission already takes initial steps in that direction. It is therefore plausible that this approach will also increasingly evolve into a central capacity market, characterised by price differentiation, (in any case mandatory) revenue clawback mechanisms, and market segmentation – resulting in a level of regulatory depth that the Monopolies Commission explicitly aimed to avoid in its conceptual design.

## 5.6 FURTHER DEVELOPMENT OF LONG-TERM MARKETS

As part of the PKNS process, Consentec (2023) developed a proposal for the further development of long-term markets.[59] This proposal is currently being discussed under the name “Strommarkt-Plus,” among others. In the context of this study, we refer to this approach as the “hedging model,” since the starting point of the concept is the upcoming introduction of a hedging obligation, which was included in the Internal Electricity Market Directive as part of the energy market reform.[60] This requirement calls for concrete implementation in national legislation. Ideally, the strengthening of consumer protection can be combined with a cost-efficient enhancement of security of supply.

A key feature of the hedging model lies in its ability to incentivise flexibility options in a technology-neutral way, making it better suited to RES-based electricity systems. The perspective that central capacity markets are primarily suited for systems that are dominated by thermal power plants – and come with significant drawbacks – while further developed long-term markets offer a more sustainable incentive structure, is also widely discussed in the US (see, for example, Cramton et al., 2024, and Wolak, 2021).

- SCOPE/VOLUME: The further development of long-term markets addresses the entire market. It is therefore a comprehensive approach to ensuring security of supply.
- TECHNOLOGICAL SELECTION: Hedging via long-term markets does not rely on technological restrictions. This makes it possible to utilise a wide variety of technologies in portfolios and virtual power plants.
- PROCUREMENT: Existing and supplementary long-term market products are purchased directly on an exchange or bilaterally by suppliers and consumers, based on their individual preferences (including willingness to pay and flexibility).
- REMUNERATION: The price of hedging products is determined by supply and demand, taking into account all available technologies – just as in today’s long-term markets. Consumers can hedge early to secure lower prices. Generators receive long-term remuneration for their capacity and electricity generation depending on the type of long-term product used.

[59] Consentec (2023) also presented an option with minimum prices in the PKNS. While it is theoretically conceivable to address the 'missing money' or 'missing markets' problem through support payments, determining the appropriate level of such payments is subject to considerable uncertainty and is difficult to justify on a fundamental basis. As a result, the scope for political influence and miscalibration is relatively high. In the remainder of this study, we therefore focus on addressing market imperfections in order to develop complete markets and price-based incentives.

[60] Electricity Market Directive (2024, Article 18): […] ensure that suppliers: (a) have in place and implement appropriate hedging strategies, to limit the risk of changes in wholesale electricity supply to the economic viability of their contracts with customers, while maintaining liquidity on and price signals from short-term markets;
(b) take all reasonable steps to limit their risk of supply failure.

- FUNDING: Hedging becomes part of the regular end-user electricity price. As a result, it places no burden on the federal budget, does not require subsidies, and does not involve any surcharge mechanism.

The further development of long-term markets represents the most technology-neutral and innovation-friendly approach among all the mechanisms discussed so far. Instead of introducing new elements into the market framework that would create additional regulatory uncertainty due to the need for continuous adjustments, this approach builds on well-established market mechanisms and aims to complete the market. As such, it enhances continuity and planning certainty. The mechanism targets the lever where a concrete incentive gap was identified during the energy crisis – allowing for a targeted intervention and avoiding a regulatory overreaction.

### Lessons Learnt from the Energy Crisis

The EU-wide debate on the introduction of a hedging obligation was sparked by the observation that some companies – particularly discount suppliers – that primarily or exclusively procured electricity for end customers on the spot market had to file for insolvency during the energy crisis. As a result, their customers were absorbed by the default supply, which then had to procure expensive electricity volumes at short notice. The energy crisis thus revealed that the risk-prone procurement strategies of some suppliers can lead to economic externalities that reduce overall welfare.

From a business perspective, however, the procurement strategies of these companies were not entirely irrational. In electricity markets with increasing shares of renewable energy, all else being equal, wholesale prices tend to decline. This incentive structure reveals a classic free-rider problem: certain actors benefit from a resource without contributing to its cost. The consequences of this behaviour only become apparent during an energy crisis, when risks materialise that these companies were not adequately prepared for.

SUPPLIERS THAT EMPLOY SERIOUS RISK MANAGEMENT PRACTICES ARE AT A COMPETITIVE DISADVANTAGE COMPARED TO DISCOUNT SUPPLIERS THAT DO NOT HEDGE THEIR SUPPLY OBLIGATIONS AND THEREBY GENERATE EXTERNAL COSTS FOR SOCIETY.

Companies that procured electricity in line with a sound risk management strategy were at a competitive disadvantage prior to the energy crisis. Consumer comparison websites primarily highlight prices per kilowatt hour. The procurement and hedging strategies underlying these offers are largely invisible to customers. On the contrary, consumers are regularly advised to switch to lower-cost suppliers to enhance competition. As a result, suppliers that entered into risk without proper hedging enjoyed a competitive advantage over those that pursued responsible risk management.

### Integrating Consumer Protection with Incentives for Capacity Providers

From a game-theoretic perspective, the free-riding incentive described above resembles a classic prisoner's dilemma (see info box in Section 2.3.1). Due to their price disadvantage compared to discount suppliers, even reputable companies are incentivized to lower prices by increasing their exposure to risk. The resulting Nash equilibrium leads to suboptimal outcomes from a societal perspective, i.e. external costs: Consumers are exposed to greater risk, and capacity providers receive lower remuneration for the risk-hedging function of their assets than they would if external risk costs were fully internalised. As a result of this market imperfection, price signals on the long-term markets remain incomplete, leading to underinvestment in capacity.

This is where the hedging obligation comes in, aiming to eliminate the free-riding incentive. In the future, companies will be required to hedge their supply obligations to electricity customers through long-term markets. As a result, demand for long-term hedging contracts will increase. This higher demand, in turn, will strengthen price signals in long-term markets. These are not artificially inflated or subsidised prices, but rather more complete prices, as they internalise the external risk costs that materialise in times of crisis. The hedging obligation thus contributes to more complete markets, which – through more comprehensive price signals – send the correct, welfare-enhancing incentives for greater capacity. Correcting the free-rider problem through a hedging obligation is an economically legitimate and sensible tool to address market imperfections.

THE HEDGING OBLIGATION CORRECTS THE IDENTIFIED MARKET IMPERFECTION OF FREE RIDING BY INTERNALISING EXTERNAL RISK COSTS, THEREBY LEADING TO A SUSTAINABLE PRICE LEVEL IN LONG-TERM MARKETS. THIS BENEFITS THOSE SUPPLIERS WHO HAVE SO FAR PURSUED A SOUND RISK MANAGEMENT STRATEGY, AS WELL AS CAPACITY PROVIDERS THAT CAN OFFER SECURE SUPPLY.

With the implementation of the hedging obligation, it will no longer be possible for suppliers to take on risk without appropriate coverage. As a result, all market participants will be better protected in times of crisis. Addressing this market imperfection helps to avoid the artificial separation between energy trading in long-term markets and capacity trading in capacity markets – a separation that would inevitably lead to further externalities and distorted incentives. The introduction of the hedging obligation is therefore a relatively simple lever to complete the market and avoid long-term inefficiencies.

At the same time, a more complete market corrects the perverse incentive to take on greater risk simply to remain competitive. With more complete markets, sound risk management is no longer a short-term competitive disadvantage. As a result, those market participants who have already developed expertise in long-term procurement and applied it through responsible risk management stand to benefit the most from the new regulation.

### Functionality of Long-Term Market Enhancement

At its core, the ongoing discussion on electricity market reform revolves around ensuring security of supply.[61] The capacity mechanisms discussed so far influence security of supply only indirectly. They support – either directly or indirectly – specific (conversion) technologies or technological features in order to ensure their availability when needed. However, in doing so, they override market-based allocation mechanisms.

Cramton et al. (2024) and Wolak (2021) highlight the distorted incentives and market power issues found in U.S. capacity markets. As a result, they propose strengthening long-term markets to replace capacity markets altogether. Germany and Europe now have the opportunity to learn from these experiences and avoid the cost-intensive mistakes made in U.S. markets. Rather than attempting to ensure security of supply through regulatory incentives in capacity markets, existing and highly liquid long-term markets can be enhanced. This approach also offers the highest compatibility with EU legislation, as cross-border electricity trading enables the use of the internal market to fulfil the hedging obligation.

[61] It is occasionally – and mistakenly – discussed as if the issue were about dispatchable capacity, building new power plants, or ensuring stable revenue streams for certain actors. These assumptions pre-empt the allocative function of markets. Such outcomes can be the result of well-designed framework conditions that provide targeted incentives. The aforementioned elements may thus become part of the solution through the right incentive system – but they are not the solution in and of themselves. Which aspects play which role is most cost-efficiently determined through the allocative function of market-based incentive systems.

The enhancement of long-term markets addresses security of supply directly by using energy hedging products (such as futures or forwards) that are entered into in advance, just as they are today. The majority of hedging will continue to take place primarily through futures and forwards. The implementation of the hedging obligation is intended to enable suppliers to hedge their supply contracts as cost-efficiently as possible in order to offer customers affordable electricity.

To ensure cost-efficient hedging of security of supply, it may be beneficial to expand the range of long-term market instruments to include option products. These essentially correspond to the reliability options already discussed in the context of other capacity mechanisms.[62] If only the existing hedging products were used, hedging would be unnecessarily expensive. However, there is no obligation to use option products. The addition of options simply makes it easier for suppliers to keep hedging costs low.

THE ENERGY INDUSTRY ALREADY HAS EXPERIENCE WITH OPTION PRODUCTS – BOTH AS A HEDGE AGAINST POWER PLANT OUTAGES, AS POWER PLANT SHARES, OR AS CAP FUTURES. DEPENDING ON THE MARKET ENVIRONMENT, THEY CAN HELP REDUCE THE COST OF HEDGING.

The use of option products is not a new concept. Hedging transactions between companies have long made use of options – for example, to hedge against power plant outages. In the 2000s and 2010s, real options were increasingly structured through financial participation in power plants, commonly referred to as “power plant slices.”

As noted in Connect (2014), an increase in price volatility is likely to drive up demand for option products to hedge against price spikes. In 2015, the EEX temporarily introduced similar products for the intraday market.[63] At the time, however, there was excess capacity in the market, which kept price volatility relatively low, and the need for options-based hedging was limited. After all, the primary motivation for using option products is to hedge against the risk of exposure to high prices.

[62] The approaches differ in detail depending on whether physical assets must be backed. This has both advantages and disadvantages. Administrative effort – and thus transaction costs – increase when, for example, prequalification is required to verify physical assets. Financial products have the advantage of potentially higher liquidity, which in turn makes the price signal more robust.

[63] The EEX cap futures were introduced as a hedge against price spikes in the intraday market (Rinck, 2015). As such, they were primarily designed to hedge against forecast deviations between the day-ahead and intraday markets, rather than serving as classical options for long-term hedging.

### INFOBOX: HOW OPTIONS WORK

An option essentially provides protection against high prices. For example, a buyer may want to avoid paying more than €500/MWh for electricity during a supply shortage. Rather than facing potentially very high prices, the buyer prefers to pay a small, regular insurance premium.

To hedge against price spikes, the buyer purchases an option – specifically, a call option – from a generator, for instance. The seller of the option commits to compensating the buyer if the market price exceeds €500/MWh during a predefined time period. In return for this protection, the generator receives a premium.

If the price does not exceed €500/MWh during the agreed period, the seller of the option does not have to compensate the buyer but may keep the insurance premium – just like in a typical household insurance policy. If no damage occurs, the insurer retains the premium despite incurring no costs.

Both parties benefit from the hedging arrangement because they may have different (risk) preferences or expectations about the future. The buyer prefers not to be exposed to the risk of a price spike and chooses to pay a fixed amount for protection. The seller, on the other hand, may consider the likelihood of a price spike to be low – or may face lower risk because they own a real asset, such as a peaking power plant. In return for assuming this risk, the seller receives a fixed payment, which they can use, for instance, to finance the power plant.

The higher the probability of price spikes, the greater the desire of suppliers to hedge against them. This increased need is reflected in a higher willingness to pay. At the same time, the opportunity cost for the seller also rises – since they could potentially benefit from these price spikes by operating their power plant. As a result, the price of the option increases. In this way, the seller exchanges the opportunity of uncertain revenues from price spikes for a fixed option premium.

The hedging obligation encourages suppliers to secure a larger share of their delivery commitments. For instance, it may have previously been sufficient to hedge only part of their supply using futures and forwards. If actual demand turned out to be higher – say, due to a cold snap – this additional demand could simply be procured on the spot market. In a system with large overcapacities, the financial risk of doing so was low because the probability of price spikes was minimal.

However, as overcapacities are reduced, the likelihood of price spikes increases.[64] This raises the financial risk for suppliers who need to procure additional electricity at short notice. Whether it is more cost-efficient to secure this need with an energy product or an option depends on the probability distribution of demand. Since a supplier cannot know in advance whether they will need to cover increased demand at a specific time, and whether high prices will prevail at that time, it may be more economical to hedge with an option rather than a future or forward. As a result, demand for options tends to rise as the probability of price spikes increases.

The hedging obligation now requires suppliers to hedge potential demand peaks from their customers. Since the probability of such demand spikes occurring at any given moment is relatively low, it would be unnecessarily costly to purchase additional futures and forwards for all time periods. Instead, it may be more cost-efficient to hedge against these less probable events using options.

This additional demand for futures, forwards, and options will be reflected in the prices of these products compared to a situation without a hedging obligation – provided there are no significant overcapacities. Under the previous system, free riding led to lower demand for hedging products, resulting in incomplete price signals on the long-term markets. Until now, demand on the long-term markets was mainly driven by individual risk preferences. The newly corrected demand through the hedging obligation therefore leads to more complete prices by internalizing risk externalities. These more complete prices, in turn, signal that investments in an adequate level of firm capacity are worthwhile. If prices in conjunction with the hedging obligation do not indicate scarcity, this is a strong indication that there is sufficient controllable capacity available.

The seller of an option also seeks to reduce the risk of having to pay the price difference in the event of a price spike. This can be achieved, for example, by holding a peaking technology as a real option. In addition to peaking power plants, this may include other flexibility options that can either generate electricity or reduce demand when needed. This approach does not create any market entry barriers, which also helps to limit market power. Furthermore, option sellers are inherently incentivized to ensure that sufficient generation capacity is available at all times – thereby reducing the likelihood of price spikes and, consequently, the likelihood of an "insurance payout".

[64] Despite higher prices, reducing overcapacity can be reasonable from a total system cost perspective – to some extent – as the highest load hours can be addressed more efficiently through flexibility options.

### Additional Market-Based Solutions for Renewable Energy Suppliers

Independent of the hedging obligation, renewable energy (RE) suppliers may also have an interest in using options products. A simple one-sided market premium essentially represents a type of option: if the price falls below X EUR/MWh, the shortfall is compensated through the one-sided premium. However, this form of support protects against low prices, not against price spikes.

Unsubsidised RE suppliers can also act as buyers of options products to hedge against price spikes on the market. They face the challenge that spot market prices tend to be relatively low when RE generation is high. If they sell part of their generation in advance via the long-term markets to secure higher prices, they run the risk of having to buy expensive electricity on the spot market in case of low production at the time of delivery. By combining long-term marketing with an options product, they can reduce their exposure to high spot prices during periods of low RE production.

Suppliers of options products, on the other hand, can use a wide range of generation technologies and flexibility options as real options to hedge their risk. Incentivising these flexibility options also supports the integration of renewable energy during periods of high RE generation. For example, biogas plants or storage assets can offer their flexibility through an option, allowing them to maximise the value of dispatchable capacity and of valuable fuels or stored energy.

This incentive system is therefore well-suited to RE-dominated systems. In contrast to central capacity markets, which structurally displace flexibility options and reduce the market value of renewables, the hedging obligation integrates RE generation with the characteristics of dispatchable capacity and flexibility options into a coherent and incentive-compatible framework.

### Implementation Options for the Hedging Obligation

The further development of long-term markets through the introduction of a hedging obligation integrates the requirements of both security of supply and renewable energy marketing. Due to this integrated incentive structure tailored to RE-dominated power systems, Cramton et al. (2024) and Wolak (2021) also propose replacing the existing capacity markets in the US with enhanced long-term markets. In these proposals, options products are likewise a key component of the hedging obligation, providing a cost-efficient way to incentivise reliable supply. Cramton et al. (2024) developed a trading system that reduces procurement risk through continuous auctions. In contrast to capacity markets, this approach allows the use of portfolio bids, which fosters technological diversity and openness to innovation.

This so-called flow trading offers a number of advantages that help reduce the burden on both market participants and the trading platform. For example, determining the appropriate price for an option can sometimes be challenging. Continuous auctions in flow trading ensure that the preferences of market participants are matched efficiently, supported by high liquidity and resulting in welfare-optimal outcomes. The main driver of this high liquidity is the obligation for suppliers to hedge their delivery contracts in advance. As a result, bids from many actors are simultaneously optimised in each auction round.

The frequency of the auctions (e.g. hourly) also enables stepwise volume adjustments based on forecast updates (e.g. for renewables and demand), avoiding the need to make large corrections in illiquid markets. Since participants' bid curves are stored in the trading system, there is no need for frequent manual adjustments. Only when new information becomes available – for instance, regarding consumer preferences – are the bid curves updated, allowing the next auction to meet preferences more effectively.

### Political-Economic Advantages of Enhanced Market Completeness

There are various options for implementing the hedging obligation in practice. However, the common strength across these different design choices lies in creating appropriate incentives for all market participants by addressing a specific market imperfection. The incentive structure created through the hedging obligation supports system efficiency, requires no technological mandates, and does not rely on central decisions regarding technical specifications or the amount of (generation) capacity required. This comes with a range of political-economic advantages, including limiting the scope for political influence over detailed market rules.

Furthermore, the approach enables market participants to make use of the widest possible range of technological solutions, making it the most innovation-friendly system for ensuring security of supply. Unlike central capacity markets, this approach does not prescribe the value of individual technologies. Instead, market actors are free to structure their portfolios in line with their needs. With regard to technological diversity as well, the model offers clear political-economic benefits.

The internalisation of security of supply into the price signal is not only beneficial from the perspective of economic incentives. The hedging obligation also eliminates the need for subsidy payments from the federal budget or any form of levy. Security of supply rightly becomes an integral part of the electricity price, which removes challenges related to financing. Since the hedging obligation is based on a requirement from the European Electricity Market Directive, it can be assumed that it does not require separate state aid approval. For this reason, it could be implemented more swiftly than other capacity mechanisms.

## 5.7 INTERIM CONCLUSION ON CAPACITY MECHANISMS

In this interim conclusion, we summarise the discussion of the various capacity mechanisms. Figure 25 presents a summary evaluation of the different capacity mechanisms.

*Figure 25: Summary Overview of Capacity Mechanism Assessments*

| | **Security of supply** | **Environmentally friendly** | **Economic efficiency** |
|---|---|---|---|
| **Selective** | − | ? / − [3] | − |
| **Central** | + / − [1] | − | − |
| **Decentral / Hybrid** | + / − [2] | + / − [2] | + / − [2] |
| **Hedging obligation** | + | + | + |

**[1] Investment incentives are positive / Risk of technological concentration is negative**

**[2] Potential of initial design is positive / Long-term politico-economic misincentives for further interventions and a slippery slope towards the central capacity market are negative**

**[3] Unclear, as it depends on specific design / Displacement of flexibility potentials and innovations is negative**

*Source: Own illustration.*

The impact of selective mechanisms depends largely on their specific design. For the purposes of this assessment, we largely follow the approach taken in the Power Plant Strategy (KWS).

- SECURITY OF SUPPLY: Selective mechanisms do not address the entire market. As a result, they lead to crowding-out of non-subsidised technologies and can contribute to an increase in technological concentration. Due to this segmentation, they are not suitable for ensuring security of supply.
- ENVIRONMENTAL COMPATIBILITY: The impact depends on the specific design. However, due to their high heterogeneity, (unconventional) flexibility options cannot be effectively promoted through capacity products. Selective mechanisms therefore tend to reduce flexibility, which negatively affects the integration of renewable energy.
- ECONOMIC EFFICIENCY: Promoting individual technologies distorts market allocation. Promoting individual technologies distorts market allocation. As a result, selective mechanisms create long-term dependencies on subsidies and a slippery slope, potentially expanding the need for support to other segments of the market. Overall, total system costs increase.

Central capacity markets cover the entire market. They require the administrative specification of a wide range of parameters, which makes them prone to political influence and distorted political-economic incentives. The attempt to limit market power inevitably leads to regulatory micromanagement.

- SECURITY OF SUPPLY: Central capacity markets support the retention of existing power plants and, if necessary, the construction of new ones. However, depending on their specific design, they may lead to a concentration in certain technologies, which can increase systemic risks (for example, supply interruptions related to hydrogen). In addition, the reduced degree of flexibility tends to lower the resilience of the power system.
- ENVIRONMENTAL COMPATIBILITY: Due to the wide range of characteristics, flexibility options cannot be fully accounted for in central capacity markets. As a result of the reduced flexibility, the integration of renewable energy into the electricity market is more difficult.
- ECONOMIC EFFICIENCY: Central capacity markets require a broad range of administrative decisions based on assumptions about the future. They tend to result in overcapacities and, through the resulting price distortions in the electricity market, displace flexibility options. As a consequence, the market value of renewables also decreases. In addition to capacity subsidies, this also increases the need for renewable energy support. More significant than the direct costs, however, are the indirect costs resulting from long-term path

dependencies and market distortions, which displace flexible and innovative technologies. Central capacity markets also tend to increase market power potential. In a dynamic electricity system, these path dependencies, distorted incentives and market power effects lead to structurally rising total system costs.

Decentralised and hybrid capacity mechanisms are prone to political interventions, which causes them to increasingly resemble central capacity markets over time, and in some cases they may be fully converted into such. Hybrid capacity markets, with their central procurement element, are already halfway towards a centralised system that tends to expand further over time due to the political-economic slippery slope.

- SECURITY OF SUPPLY: Conceptually, decentralised and hybrid capacity mechanisms are capable of ensuring security of supply effectively. However, if politically desired market outcomes fail to materialise, the likelihood of political adjustments is high. As a result, they tend to lead to the same risks of technological concentration as central capacity markets in the long run.
- ENVIRONMENTAL COMPATIBILITY: Due to their decentralised incentive structure, decentralised – and to a slightly lesser extent hybrid – capacity mechanisms can promote flexibility options. However, as discussed, they tend to experience political recalibrations if market outcomes deviate from political expectations, which may ultimately result in similar crowding-out effects as seen in central capacity markets.
- ECONOMIC EFFICIENCY: In theory, decentralised – and to a significant extent also hybrid – capacity mechanisms have the potential to ensure security of supply in a cost-efficient manner. However, due to the political-economic slippery slope towards more centralised capacity markets, they tend to produce similar market distortions and, over time, lead to a comparable increase in total system costs.

The implementation of the hedging obligation has the potential to address existing distortions and market imperfections at their root. The risk externalities created by some suppliers due to insufficient hedging in the long-term markets can be internalised through this obligation. The resulting complete price signals incentivise investment in appropriate technologies for a secure electricity supply. As such, the hedging obligation is well suited as a sustainable market design – both for the energy transition and beyond.

- SECURITY OF SUPPLY: By requiring suppliers to hedge expected load profiles comprehensively, all available technologies can contribute to securing electricity supply. The completed price signals reveal consumers' willingness to pay for supply security.
- ENVIRONMENTAL COMPATIBILITY: The market-based incentive structure allows for the effective use of all (including unconventional) flexibility options. The hedging obligation stimulates investment in and greater utilisation of available flexibility, enabling better integration of renewable energy sources.
- ECONOMIC EFFICIENCY: By correcting existing distortions and market imperfections, the hedging obligation enables completed price signals to cost-efficiently incentivise supply security. The incentive system is characterised by broad technological openness, allowing innovative technologies to play a role in securing supply. Compared to other capacity mechanisms, the hedging obligation represents a market-based approach that delivers the lowest total system costs and requires no funding from the federal budget or through levies.

The analysis of the various capacity mechanisms reveals that the key differences lie in their susceptibility to political-economic distortions. For example, the decision to introduce a capacity market would likely incentivise investment restraint (wait-and-see behaviour) until all design parameters are reliably and legally defined. As a result, no new capacity would be added during the critical years ahead. In contrast, the hedging obligation could be implemented in the near term, enabling new investments to proceed without delay.

# 6 Recommendations for the Further Development of the Market Design

SUSTAINABLE DEVELOPMENTS

By further developing the framework conditions of the market design and addressing current market imperfections through the introduction of a hedging obligation, security of supply can be organised on a market-based foundation.

The further development of the market design is not only about implementing specific measures to ensure security of supply. The smooth functioning of the market also depends on the framework within which these measures can take effect. It is sometimes argued that the transformation requires a concrete plan. In contrast, we argue that what is needed are targeted and flexible framework conditions that allow incentives to guide behaviour towards the desired objectives – while leaving room for the integration of innovation at any time.

In Section 2.3.2, we discussed the various forms of ambiguity currently affecting investment decisions. These uncertainties act as frictions that inhibit target-oriented incentives. For this reason, supportive framework conditions are essential to ensure the effectiveness of market-based signals. It is particularly important to avoid introducing distortions that would later require compensation through subsidies. Such frictions in market functioning give rise to externalities that – in different ways – increase total system costs and thereby reduce overall welfare.

A SUSTAINABLE MARKET DESIGN REDUCES DISTORTIONS INSTEAD OF COSTLY SUBSIDISING AGAINST THEM AND THE EXTERNALITIES THEY CREATE.

When designing the regulatory framework, market processes and price signals should be as complete and incentive-compatible as possible. This means internalising externalities of all kinds to enable system-serving incentive effects. As a result, certain forms of explicit support can be avoided – support which would otherwise become targets for political influence, raise financing issues, and inevitably increase uncertainty. In contrast, complete price signals reduce uncertainty and help to manage the increasing complexity of the electricity system in an evolutionary and welfare-enhancing manner.

In the following section, we focus on the design of stable and goal-oriented framework conditions. We then propose a market-based incentive system for ensuring security of supply.

## 6.1 REDUCING AMBIGUITY AND ALIGNING INCENTIVES WITH OBJECTIVES

To enable investment incentives to take effect, we begin by discussing how ambiguity and misaligned incentives can be minimised. These considerations offer an alternative to planning and subsidising every single system component through administrative micromanagement. Such detailed steering creates frictions and prevents the establishment of an effective incentive system, ultimately increasing total system costs.

The approach of internalising both negative and positive externalities serves to design system-oriented incentives that contribute to increased social welfare. At its core, the objective is to create framework conditions that generate incentives aligned with overarching policy goals.

### 6.1.1 Aligning Framework Conditions and Incentives

For incentives to be effective, various levers must be adjusted to jointly promote behaviour aligned with overarching goals. In doing so, it is important to consider not only economic principles but also political-economic incentives.

#### Learning from Crises and Reducing Political Uncertainties Through Preparatory Measures

Reliable political framework conditions are essential for market-based incentives to take effect. As discussed in 2.3.2, the introduction of revenue caps and debates about market design (including proposals to abolish the merit-order principle) have increased uncertainty among market participants. While the implications of a shortage of primary energy carriers are not directly comparable to those of a shortage of conversion technologies, concerns about potential interventions in price formation are understandable.

In times of crisis and scarcity, when segments of the population risk falling into financial hardship and companies may be forced to suspend production, it is not realistic to expect political decision-makers to remain passive. This apparent dilemma can be addressed – not by interfering with the incentive system, but by mitigating the social and economic consequences of crises.

The future is inherently shaped by uncertainty, and specific developments are impossible to predict. Regardless of the actual triggers, situations may arise at any time in which state intervention becomes necessary. In such cases, however, political decision-makers should avoid undermining those market mechanisms that are best equipped to address specific scarcities by sending targeted price signals.

RELIABLE POLITICAL FRAMEWORK CONDITIONS ARE ESSENTIAL FOR MARKET-BASED INCENTIVES TO UNFOLD THEIR FULL EFFECT.

Instead, it is possible to prepare the market design for such situations in a targeted way through appropriate measures. While the specific nature of future crises cannot be predicted, a transfer mechanism can be established that is adaptable to a range of crisis scenarios and capable of cushioning social and, if necessary, economic hardship.

During the pandemic and the energy crisis, it was not possible to implement sufficiently targeted measures to support vulnerable households and businesses. As a result, broad relief measures were adopted, alongside market interventions in the electricity sector, which placed a burden on the federal budget and led to market distortions. These experiences offer important lessons and underscore the need for anticipatory mechanisms. Chief among these is the development of a state-run payment infrastructure that enables rapid and straightforward transfer payments to households and businesses in times of need.

This financial infrastructure could also be used to mitigate energy- and climate-related burdens. For example, the energy system will rely on the import of hydrogen (and hydrogen-based derivatives), and it is already foreseeable that this will entail significant cost and price risks. Likewise, $CO_2$-costs may rise sharply at times. The proposed transfer mechanism could also be used to buffer temporary shocks arising from limited availability of primary energy carriers or generation capacity.

This eliminates the need for policymakers to implement ad hoc crisis measures, which inevitably lead to unintended consequences in the form of externalities and market distortions.

By ensuring that price signals remain an integral part of the allocation mechanism, market participants are empowered to develop solutions that address the underlying scarcity as efficiently as possible. The transfer mechanism enables external effects to be avoided by reducing the need for political intervention, while internalising the incentive for crisis preparedness into the price signal. In doing so, it helps establish the conditions for more complete markets and more effective price incentives.

This transfer mechanism also sends a strong signal to market participants that incentive signals are reliable, as policymakers have the tools to respond appropriately to crises. As a result, the perceived need for market interventions diminishes from a political perspective. The mechanism therefore serves as a useful instrument for safeguarding the stability of market-based incentive structures.

Reliable price signals, in turn, stimulate investments that enhance the resilience of the energy system and thereby help to prevent future crises. The effectiveness of the framework conditions and the incentive mechanism we will discuss in Section 6.2 is strengthened by the presence of such stable and credible foundations.

### System-Friendly Incentives for Prosumers and Flexible Consumers

Flexible consumers play a crucial role in the market-based organisation of security of supply. Therefore, it is essential to eliminate any frictions that limit either price signals or the responsiveness of these consumers.

For energy-intensive industrial consumers, individual grid fees pursuant to Section 19 (2) Sentence 2 of the German Electricity Grid Charges Ordinance (StromNEV) are particularly relevant in shaping the economic incentives to respond to wholesale electricity price signals. Initial steps have already been taken towards greater flexibility, such as the removal of selected hours of the day from the calculation of "baseload conformity" (BNetzA, 2024b). These adjustments are an important and welcome first step towards unlocking additional flexibility potential.

Looking ahead, prices during so-called "Dunkelflauten" (extended periods of low renewable generation) are expected to remain elevated for longer durations. During such periods, industrial consumers should at least have the option to adjust their production schedules accordingly – without incurring higher grid fees as a penalty for reducing their load.

The existing scheme for "atypical grid usage" (Section 19 (2) Sentence 1 StromNEV) already allows for more electricity consumption outside of defined peak load time windows, as these periods are excluded from the calculation of demand charges. Both of these regulatory frameworks should be further developed to encourage greater flexibility – without jeopardising the competitiveness of those companies that currently benefit from them.

If low primary energy availability leads to higher prices, it is irrelevant whether the scarcity results from a lack of wind, solar, or hydrogen. What matters is that price signals can take effect. This means that reducing electricity consumption should not be penalised through additional cost burdens. Flexible consumers generate positive externalities by helping to stabilise the price level.

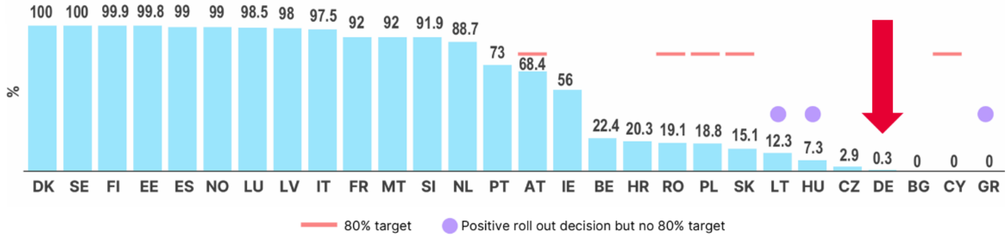
Industrial consumers should be given the opportunity to sell electricity previously procured through long-term contracts at a profit on the spot market during periods of high prices, thereby contributing to the improvement of the supply situation. This would allow proactively planned optimisation and maintenance work to be carried out flexibly in order to make optimal use of the high-price window. Instead of scheduling such activities rigidly in advance, an agile approach would enable industrial consumers to seize emerging opportunities more effectively. The ongoing digitalisation of industry (Industry 4.0) will support this shift.

FLEXIBLE CONSUMERS CREATE POSITIVE EXTERNALITIES BY REDUCING OVERALL SYSTEM COSTS, WHICH ALLOWS INFLEXIBLE CONSUMERS TO BENEFIT FROM LOWER PRICES AS WELL.

Over time, in addition to internal organisational learning, investments will be made – such as in intermediate storage – that further increase the flexibility of production processes. As a result, flexible consumers will gradually enhance the resilience of the energy system. Through systematic learning – not only by producers but also by consumers – on how to deal with scarcity situations and even benefit from emerging opportunities, the system becomes antifragile.

The same principle fundamentally applies to private consumers. As they learn to behave more flexibly, they generate various positive externalities. However, in order for consumers to develop conscious consumption habits, access to measurement data via smart meters is essential. Figure 26 compares the smart meter penetration rates across EU Member States.

*Figure 26: Smart meter rollout in the European member states (2022)*




*Source: Acer (2023).*

Electricity consumers who lack access to system state information – such as price signals – automatically generate negative externalities. An effective smart meter rollout can reduce these existing market imperfections. In contrast, price-elastic consumers help lower total system costs, benefiting even those consumers who are unable (or unwilling) to behave flexibly through reduced prices. Moreover, flexible consumers enhance the resilience of the energy system. Their ability to respond appropriately to scarcity prepares the system better for future crises.

Smart meters provide access to information and thus address the first prerequisite for system-serving behaviour. The second requirement is access to dynamic electricity tariffs. According to § 41a of the German Energy Industry Act (EnWG), all suppliers will be obliged to offer dynamic tariffs from 2025 onwards.[65] However, smart meters are the foundation for enabling system-serving behaviour. Therefore, the smart meter rollout should be accelerated to establish the necessary conditions for dynamic electricity tariffs.

To incentivise system-serving behaviour by decentralised generation and consumption technologies (e.g. rooftop and balcony PV, heat pumps, electric vehicles, and residential batteries), dynamic tariffs should be used. Neon (2024) estimates that dynamic pricing could reduce household electricity costs for operating heat pumps by 24% and for electric vehicles by up to 70%. FfE (2024) calculates that flexible households could save around EUR 600 per year. In parallel, lower reliance on gas and hydrogen power plants could result in EUR 4.8 billion in system cost savings. In this way, the private economic benefits for households are aligned with the overall system benefit (see Section 6.1.2 for the integration of locational incentives).

### Strengthen Emissions Trading as an Incentive Instrument for Decarbonisation

For investments in decarbonisation technologies, the binding nature of $CO_2$-reduction targets is the key incentive. The reduction pathway of the European Emissions Trading System (ETS) and the associated increase in $CO_2$-prices are crucial investment signals. This applies to the existing sectors covered by ETS I and, in the future, also to the heating and transport sectors under ETS II. For these investment signals to unfold their full effect, it is essential that there is no uncertainty about the binding nature of the reduction trajectory.

[65] In Norway, over 90% of household customers currently use dynamic electricity tariffs (Acer, 2023a).

Wherever there are opportunities to make the reduction path more credible and politically binding, they should be pursued.

Decarbonisation via the ETS has the advantage of incorporating feedback mechanisms that can cushion market tightness. In contrast, a fixed phase-out date for coal-fired power plants, for example, is structurally prone to uncertainty.[66]

How fixed dates can increase uncertainty for investments in low-emission technologies is illustrated by the Emission Performance Standard (EPS). The extension of the EPS in the Polish capacity market has negatively impacted investment security for decarbonisation technologies by creating unpredictable political uncertainty. Given the precedent of extending the EPS from 2025 to 2028, it is now rational to expect further extensions of capacity payments for coal-fired power plants within the capacity market.

It is even conceivable that the introduction of a capacity market in Germany could lead the then-responsible federal government to advocate for a further postponement of the EPS. After all, it would be subject to political incentives to use the available options at that time to ensure supply security at the lowest possible cost. In this respect, there is a risk that the introduction of a capacity market could create counterproductive climate policy incentives.

THE INHERENT MARKET FEEDBACK OF THE ETS ALLOWS FOR THE GUARANTEE OF SUPPLY SECURITY – UNLIKE A FIXED PHASE-OUT DATE.

In contrast, a market-driven coal phase-out is moderated by the market's natural tendency toward equilibrium. If capacity shortages lead to higher prices on the electricity market, coal-fired power plants may continue operating for a limited time. At the same time, the higher prices incentivize investment in decarbonization technologies, which, once entering the market, gradually displace increasingly uneconomic coal power plants.

For these market incentives to be effective, the reliability of the ETS is crucial. For example, calculations in the Security of Supply Monitoring Report (BNetzA, 2023b) indicate that, under the modelling assumptions used, a largely market-driven coal phase-out could already be achieved by 2028. Rather than implementing an administratively accelerated coal phase-out, it would be more appropriate to rely on a robust emissions trading scheme to provide effective decarbonization incentives.

[66] See discussion on ambiguity in Section 2.3.2.

If decarbonization incentives are allowed to operate in this way, it becomes all the more important to establish mechanisms that can cushion social and economic hardships during times of crisis. Without such mechanisms in place, any intervention in price formation during high-price phases would be anticipated by market participants, thereby weakening the intended incentive effects.

### Target-Oriented Principles for Scaling Up the Hydrogen Market

Based on current knowledge, hydrogen is expected to play an important role in ensuring security of supply in the future. However, the extent of this role – and which technologies may complement or substitute it – should be determined through the market-based allocation process. Pre-empting long-term allocation decisions based on today's assumptions about the late 2030s and 2040s could result in costly misallocations. It is therefore crucial to carefully align incentive systems to avoid creating an expensive and insecure supply system, even if the underlying intentions are sound.

Government support for the development of a core hydrogen network can be a suitable measure to enable the ramp-up of the hydrogen market. Supply-side measures – such as funding the development of import infrastructure – can also be economically justified to facilitate market entry. To ensure the reliability of the various technologies, it is advisable to thoroughly test all necessary system components. For this purpose, the government can provide research funding and support demonstration projects.

However, the use of subsidies to promote the operational consumption of hydrogen for power generation should be avoided, as this would create significant cost risks and market distortions. Hydrogen Contracts for Difference ($H_2$-CfDs) aim to incentivise hydrogen consumption by subsidising hydrogen-based electricity generation down to the cost level of natural gas and $CO_2$. In theory, this would replace fossil-based power generation with climate-neutral alternatives. However, the risk of unintended consequences is considerable.

The use of $H_2$-CfDs for hydrogen-based power generation results in a decoupling of hydrogen demand from the hydrogen market. By covering the cost difference between hydrogen and natural gas for electricity generation, the demand for hydrogen becomes inelastic. This means that no matter how high the hydrogen price rises, the demand for hydrogen in the power sector remains unchanged – since it responds only to natural gas and $CO_2$-prices, not to the actual hydrogen market price.

Since the hydrogen market is expected to remain relatively illiquid for the foreseeable future, price reactions could be significant if hydrogen is used for power generation regardless of its market price. As previously discussed, LNG prices rose by 40% in 2023 following strike announcements in Australia. Given the substantially lower liquidity of the hydrogen market, even a multiplication of prices is conceivable. The resulting additional costs would represent an incalculable financial risk for the federal budget, which would be responsible for covering the difference between the gas price (including $CO_2$-costs) and the actual cost of the hydrogen used.

HYDROGEN DIFFERENCE CONTRACTS CREATE AN INCALCULABLE COST RISK FOR THE FEDERAL BUDGET.

A second cost and security risk arises from the crowding out of more cost-efficient decarbonisation technologies, flexibility options, and innovations by subsidised hydrogen-based power generation. Such hydrogen support would also indirectly impair the integration of renewable energy sources. Market distortions of this kind would create a system that becomes structurally dependent on hydrogen-fired generation rather than incentivising more flexible and cost-efficient alternatives.

If subsidies were to expire before hydrogen prices drop substantially, this approach would lead to stranded investments, as many technologies would be ready to replace hydrogen-fired plants but could not enter the market due to earlier market distortions. From a political-economic perspective, this creates a path dependency that increases the likelihood of extending the subsidies indefinitely, resulting in a lasting fiscal burden for the federal budget.

In the context of the debate on the European electricity market design, there were discussions – primarily motivated by consumer protection concerns – about whether the marginal-cost-based merit order should be replaced by an alternative approach. Fortunately, this idea was ultimately rejected, as the long-term consequences for overall system costs would be severe due to the resulting distortion of market incentives.

ONLY WHEN HYDROGEN IS USED BASED ON COST CONSIDERATIONS CAN FLEXIBILITY OPTIONS AND OTHER (INNOVATIVE) TECHNOLOGIES BE INCENTIVISED – THUS STRENGTHENING SECURITY OF SUPPLY.

However, the use of hydrogen contracts for difference ($H_2$-CfDs) would have a similar effect, as the merit order would no longer be based on actual generation costs. Hydrogen should only be used in the power market when no more cost-efficient alternative is available to meet demand. That is the core principle of a cost-based merit order.[67]

It does not matter whether hydrogen becomes competitive because of rising $CO_2$-prices or falling hydrogen prices. What matters is the consistent application of the cost-based merit order, which is essential for ensuring cost-efficiency in both the short and long term in a market-based system.

Long-term cost efficiency also requires incentives for technical innovations that contribute to an affordable energy transition and thereby enhance public acceptance. However, prices must always reflect the true costs and underlying scarcity in order to encourage more cost-efficient alternatives.

The cost-based use of hydrogen in scarcity situations encourages complementary technologies, resulting in a more diversified technological mix. This diversification strengthens the resilience of the power system, as stored hydrogen lasts longer when other technologies can help meet demand. A broader technology portfolio enhances security of supply and makes the system less vulnerable to crises.

If, instead of relying on market-based allocation, hydrogen power plants are subsidised through capacity mechanisms, their share in electricity generation will increase – potentially resulting in a more fragile system due to unintended consequences. By crowding out complementary technologies and flexibility options, the electricity system becomes increasingly dependent on a secure supply of sufficient quantities of hydrogen. Yet it remains uncertain how the hydrogen market will evolve, what volumes will become available, at what prices, and from which countries. In light of these uncertainties, creating such a dependency through subsidies appears to be a risky strategy – especially at a time when the availability of innovative technologies is growing at an unprecedented pace.

IN ORDER FOR HYDROGEN POWER PLANTS TO FULFIL THEIR ROLE AS BACK-UP GENERATION, IT IS ESSENTIAL – IN THE CASE OF CAPACITY SUPPORT – THAT THEY ARE ABLE TO FULLY COVER THEIR FIXED COSTS WITHOUT RELYING ON OPERATING SUBSIDIES THROUGH H2-CFDS. THIS ALLOWS PRICE SIGNALS IN THE ELECTRICITY MARKET TO INCENTIVISE COST-EFFICIENT ALLOCATION.

A selective support scheme for power plants is not advisable for the reasons discussed above. However, if hydrogen power plants are to be supported

[67] All competitive markets are characterised by a cost-based supply curve. The merit order is therefore not a unique feature of the electricity market. Deviating from this market-based principle inevitably leads to higher societal costs due to short- and long-term misallocations.

through capacity mechanisms, they must be able to fully recover their fixed costs so that they are not reliant on contribution margins from the electricity market. Under this condition, operational support through $H_2$-CfDs becomes unnecessary, and these plants can fulfil their intended role as back-up generation. The use of hydrogen for electricity generation would then act as a scarcity signal, incentivising more cost-efficient solutions. This approach helps to contain the rise in total system costs.

If, however, these plants are initially allowed to operate on natural gas, it would distort the market to the detriment of other technologies – such as flexibility options (see discussion in Section 5.1). In order for the use of hydrogen during periods of low renewable generation (so-called "Dunkelflauten") to generate system-serving incentives without triggering political intervention in price formation, the crisis response mechanism discussed earlier proves to be a helpful tool.

### Enabling Fast Realisation Times for Investments

Market participants have various options to respond to scarcity signals. For instance, they can conclude contracts with flexible consumers, invest in battery storage, or develop new generation capacity. These different options have varying techno-economic characteristics and implementation timelines.

Adjusting a supply contract with a flexible consumer can, in theory, be done within minutes. At the other end of the spectrum are power plant investments, which may take several years to fully implement. To enable market participants to respond quickly to scarcity signals, it is essential that administrative processes are designed to be as efficient as possible.

In the press release announcing the Power Plant Strategy (BMWK, 2024), the government stated that planning and permitting procedures for the power plants included in the strategy would be substantially accelerated. However, such procedural streamlining should not be limited to KWS plants alone, but ideally apply to all technologies that can contribute to a cost-efficient assurance of electricity supply.

Market dynamics benefit from short implementation timelines. It would therefore be useful to establish an agile approach that continuously identifies – based on the latest experiences – those procedural steps that would benefit most from acceleration. In doing so, a continuous improvement process could be put in place to sustainably support the smooth functioning of the market.

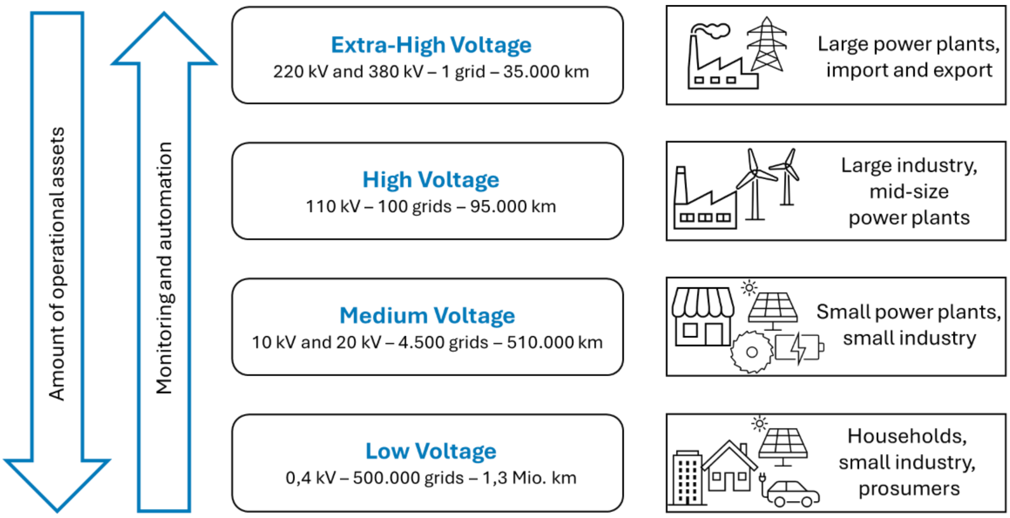
## 6.1.2 Spatial Allocation Incentives

As discussed in Section 2, the current phase of transformation is changing the composition and interactions of various system components. We are seeing an increase in onshore and offshore wind installations, with a concentration in the north, as well as a rise in photovoltaic systems, particularly concentrated in the south. In addition, the number of decentrally distributed renewable energy generation assets (especially rooftop PV systems) is growing, along with new consumption technologies and flexibility options (primarily electric vehicles, heat pumps, and home battery storage), which are mainly connected at the low-voltage level.

### Background and Current Developments

As the use of different generation and consumption technologies increasingly diverges in time, the need for electricity transport is rising across all voltage levels. Figure 27 illustrates the various voltage levels and their characteristics.

*Figure 27: The Voltage Levels of the Grid Infrastructure and Their Characteristics*




*Source: own illustration according to Wawer (2022).*

The expansion of transmission capacity cannot keep pace with the rapid growth in generation and consumption assets. This growing scarcity of transport capacity leads to external effects. The two most relevant measures differ by grid level:

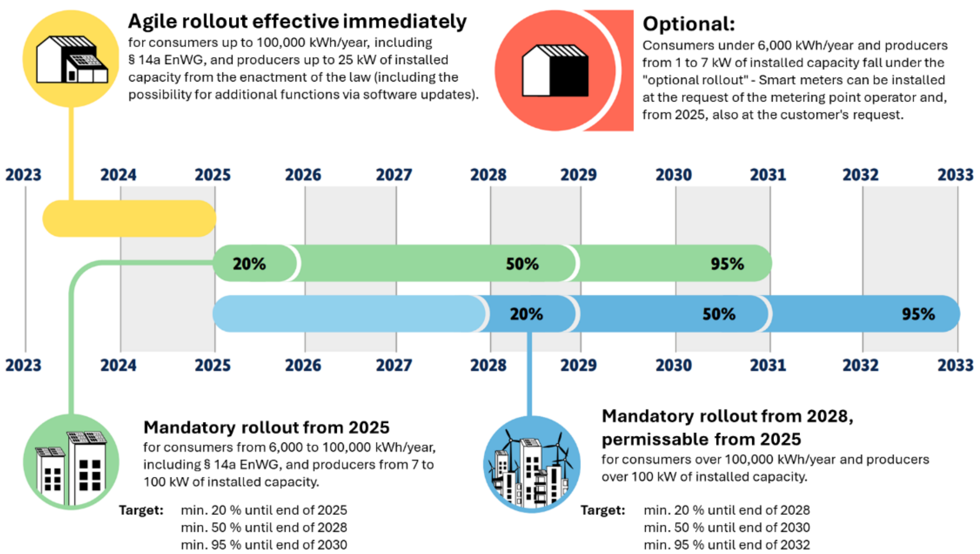
- At the transmission level, redispatch is used as an operational measure to manage grid congestion. This includes the curtailment of renewable energy plants. To ensure that sufficient redispatch capacity is available, power plants scheduled for decommissioning but located at grid-relevant sites are transferred to the grid reserve.

- At the distribution level, Section 14a of the Energy Industry Act (EnWG) provides a mechanism to continue connecting new consumption technologies to the grid. In case of an imminent overload, these assets can be curtailed (i.e. their power consumption reduced to 4.2 kW).

To enable distribution system operators to ensure secure grid operation through demand-side curtailment, significant improvements in data quality are required. While measurement data at higher voltage levels already meets high standards, comparable data quality is still lacking at the distribution level.

In the coming years, however, sensor technology in transformer stations will be upgraded to meet the requirements of Section 14a EnWG. In combination with the smart meter rollout, distribution system operators will soon have access to high-quality data that allows them to continue ensuring safe and reliable grid operation. Figure 28 illustrates the timetable for the smart meter rollout.

*Figure 28: Statutory Smart Meter Rollout Schedule*




*Source: BMWK (2023).*

The improved data quality will soon enable grid constraints in the distribution network to be addressed securely. Nevertheless, the external effects resulting from curtailment, redispatch, and demand-side throttling lead to welfare losses until the grid infrastructure is sufficiently expanded.

### Internalising External Effects of Grid Congestion[68]

External effects represent a market imperfection that can impact not only economic efficiency but also supply and system security. In order to incentivise system-supportive behaviour among market participants, it is essential to internalise these externalities through appropriate market-based incentives. Internalisation also increases overall societal welfare, as relevant actors can respond to price signals in line with their preferences, rather than being curtailed arbitrarily.

A well-known example of internalising negative externalities is the pricing of $CO_2$-emissions. Positive externalities, by contrast, can be priced through subsidies or premiums to encourage their beneficial effects. However, when pricing external effects, it is crucial to determine the appropriate level of pricing and remain aware of misaligned potential political-economic incentives.

So far, the internalisation of external effects arising from the use of transmission infrastructure has primarily been discussed in the context of nodal pricing systems. In such systems, congestion in the transmission grid – typically at the extra-high voltage level, and in some cases the high voltage level – is internalised by assigning a distinct price to each grid node.

However, nodal pricing is not suitable for managing congestion on the lower-voltage grid levels. Looking ahead, a significant share of network congestion is expected to arise in the distribution grid, due to the rapid expansion of decentralised generation and consumption technologies. For this reason, it would be more effective to implement a system for internalising external effects that is capable of addressing congestion management across all voltage levels of the electricity grid.[69]

### Dynamically Adjusting Network Tariffs to Incentivise Positive Demand-Side Effects

Social welfare is fundamentally based on the fulfilment of human needs. The utility that individuals derive from consuming a good varies not only across individuals but also for each individual over time. For overall societal welfare to

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[68] The potential splitting of the uniform German bidding zone has been under discussion for some time. There are many economic and political arguments both for and against such a split, which will not be explored in detail here. The tools proposed in this section are intended to expand the solution space in case political decision-makers choose to maintain the current uniform bidding zone.

[69] To this end, flexibility markets are occasionally discussed. However, these have proven unsuitable for managing grid congestion due to distorted incentives caused by inc-dec gaming (see, for example, Neon et al., 2019). While the internalisation of externalities helps to reduce grid congestion, flexibility markets can inadvertently lead to an increase in congestion.

be maximised, the utility of consumption must exceed the societal cost of that consumption. To achieve this, individuals need both information about the system's status and incentives to align their behaviour with the needs of the system. Complete price signals combine information and incentives in a way that allows system-oriented behaviour to be orchestrated effectively. Therefore, to enhance societal welfare, it is sensible to ensure that consumers have access to complete prices that internalise all relevant costs.

Decentralised consumption technologies typically exhibit a high degree of simultaneity. Heating demand rises when it is cold, and electric vehicles are often charged after work. To prevent cumulative demand from exceeding available generation capacity, these technologies should be combined with dynamic electricity tariffs. This synchronises demand with generation availability and ensures that price signals dampen load peaks.

However, since wholesale electricity prices are uniform across Germany, local bottlenecks in the transmission infrastructure can still occur. This is especially true when nationwide low prices – driven by high renewable feed-in – lead to increased local demand, potentially causing or exacerbating congestion on one or more grid levels. To internalise the external effects of constrained transmission infrastructure, network tariffs can be designed dynamically. Time-differentiated network charges are already in use in several European countries (see Figure 29).

*Figure 29: Time-Differentiated Network Tariffs in the Transmission and Distribution Grid*

| | AT | BE | EE | FI | FR | PL | PT | ES |
|---|---|---|---|---|---|---|---|---|
| January | ◑ | ◐ | ◐ | ● | ● | ◑ | ● | ● |
| February | ◑ | ◐ | ◐ | ● | ● | ◑ | ● | ● |
| March | ◑ | ◐ | ◐ | ◑ | ● | ◑ | ● | |
| April | | ◐ | | | | | | |
| May | | | | | | | | |
| June | | | | | | | | |
| July | | | | | | | | ● |
| August | | | | | | | | |
| September | | | | | | | | |
| October | ◑ | | | | | ◑ | | |
| November | ◑ | ◐ | ◐ | ◑ | ● | ◑ | ● | |
| December | ◑ | ◐ | ◐ | ● | ● | ◑ | ● | ● |

◐ Transmission-only, ◑ Distribution-only, ● Transmission and Distribution

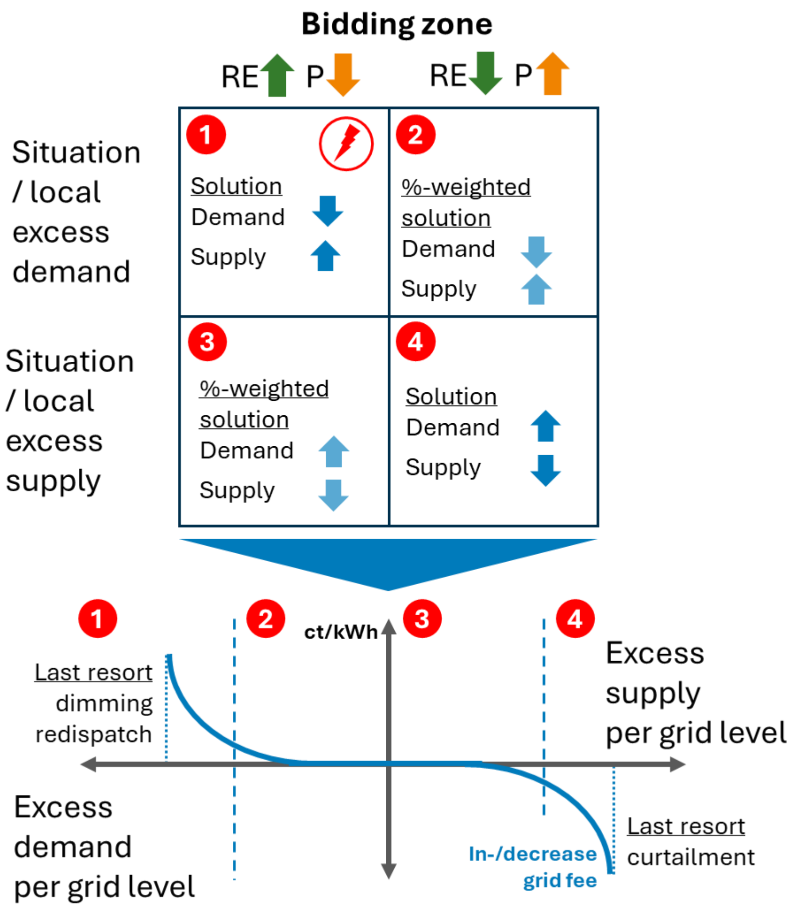
*Source: Acer (2023b).*

Depending on whether a region is experiencing a surplus or a scarcity of electricity, network tariffs can be adjusted either upward or downward. It is important to note that a region may be a scarcity region at one point in time and a surplus region at another. To ensure an effective system-oriented incentive, network tariffs should not be determined based on fixed time windows, but should instead be dynamically and situationally designed. In principle, this incentive should apply to all consumers – unless technical limitations or concerns about competitiveness argue against it. For example, in periods of high regional feed-in from renewables, network tariffs should not discourage additional electricity consumption within that region.

However, the determination of network tariffs should not be confused with a technical control signal. Demand response is based on human preferences. As such, incentives for demand-side reactions and the collection of data to measure price elasticity occur simultaneously. This interplay makes the incentive system a complex one, whose exact effects cannot be planned ex ante. The development of such an incentive system is therefore evolutionary in nature and will likely require ongoing fine-tuning.

The setting of network tariffs should take place prior to the day-ahead market in order to allow demand forecasts to be reflected in bidding behaviour on the wholesale market. Figure 30 presents a 2x2 matrix showing the relevant regional conditions and corresponding states, with the coordinate system indicating the appropriate network tariff adjustment.

*Figure 30: Design Logic of Dynamic Grid Fees*




*Source: Own illustration.*

Figure 30 illustrates how network tariff surcharges and discounts can be determined based on the level of renewable energy (RE) generation and the market situation relative to the local grid situation:

- SITUATION 1: High RE generation in the bidding zone leads to low wholesale prices, while local demand exceeds grid capacity on the corresponding network level. This is the most critical challenge during the transformation phase. One solution is to either reduce demand or increase local supply. Network tariffs are situationally increased on the respective grid level to incentivise demand reduction. For prosumers, covering demand with self-generation (e.g. from stored electricity) may be economically attractive in such situations.
- SITUATION 2: Low RE generation in the bidding zone leads to high wholesale prices, yet local demand may still exceed grid capacity. Depending on the likelihood and severity of grid stress, it may be sensible

to moderately increase network tariffs to incentivise demand reduction or encourage self-generation.

- SITUATION 3: High RE generation in the bidding zone leads to low wholesale prices, and locally there may be a surplus of supply on the respective grid level. Depending on probability, it may be appropriate to moderately reduce network tariffs to encourage increased demand or reduced self-generation.
- SITUATION 4: Relatively low RE generation in the bidding zone results in moderately high wholesale prices, while local grid conditions may still exhibit a surplus of supply. In this case, network tariffs are reduced situationally to stimulate demand or disincentivise self-generation.

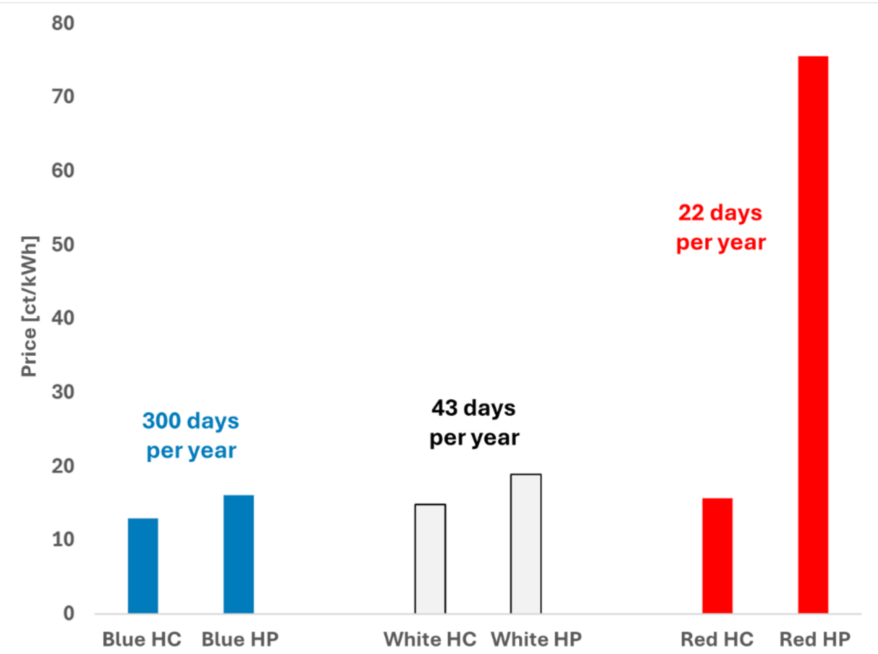
Situations 3 and 4 in Figure 30 occur when regional renewable energy (RE) generation exceeds available transmission capacity. In this context, Neon (2023) developed a concept on behalf of Agora Energiewende, proposing that network tariffs should be reduced to zero ct/kWh in cases where curtailment of wind energy installations (WEA) is expected. This approach helps stimulate local demand and reduce the need for curtailment.

The more critical scenario, however, is a demand surplus due to network congestion, where insufficient generation is available within the affected grid region (Situation 1). On the distribution grid level, this would typically trigger curtailment measures such as dimming under § 14a EnWG. The drawback of this approach is that it may result in curtailing consumers who place high value on consumption at that particular time, while indifferent consumers may continue to consume electricity.

As a measure of last resort, dimming by distribution system operators (DSOs) and redispatch by transmission system operators (TSOs) is necessary to ensure grid stability. However, raising network tariffs in foreseeably critical situations could reduce demand from flexible consumers, thereby lowering the need for dimming and redispatch measures. In this way, consumers who derive high utility from consuming electricity at that time could continue to do so, while indifferent consumers might shift their consumption to other periods.

When designing such dynamic network tariffs, considerations around industrial competitiveness and technical constraints must be taken into account. As already shown in Figure 29, there are examples of dynamic network tariff models in other European countries. Figure 31 illustrates this by showing the time-dependent pricing structure of EDF's Tempo tariff as a practical example.[70]

*Figure 31: Tariff Structure of the EDF Tempo Tariff*




*Source: Own illustration, data from EDF (2024a).*

The price of the most expensive time window is nearly six times higher than that of the cheapest. Customers are informed the day before which price level will apply the following day. According to EDF, customers on the TEMPO tariff reduce their consumption by an average of 23% on high-price days.[71]

High-price time windows also incentivize self-consumption. For example, using a home battery system becomes financially attractive, as it allows customers to reduce or entirely avoid consumption during expensive periods. From a system perspective, this is beneficial because self-generation eases the burden on both the electricity market and the power grid.[72]

Dynamic electricity tariffs combined with dynamic network charges create system-friendly incentives for prosumers. They are therefore an important measure to improve cost-efficiency and security of supply.

[70] Based on the product description, it is not clear whether the variability in end-customer prices is solely driven by wholesale prices or whether grid congestion is also taken into account. From the perspective of influencing customer behaviour, however, the basis for price variability is irrelevant.

[71] EDF (2024b).

[72] Customers with self-generation, however, are charged a surcharge of €8.88 per year (EDF, 2024a), presumably to compensate for network charges.

The exact design of dynamic network charges requires more detailed analysis. However, a general principle should apply: network operators must not generate additional revenue through this measure, but should instead redistribute the network charges that would arise anyway across time and space.

In addition to price incentives via dynamic electricity tariffs and dynamic network charges, it remains essential that network operators retain last-resort tools. In the case of a supply surplus, this means the ability to curtail renewable energy installations. In situations of demand surplus, this refers to load reduction ("dimming") under § 14a EnWG on the distribution grid level, and the use of redispatch on the transmission grid level.

### Reducing Distorted Incentives on the Supply Side

As previously described, redispatch measures are used to ensure the secure operation of the electricity grid.[73] In a redispatch situation, generation in surplus regions is curtailed, while generators in the congestion region typically ramp up their output. In return, generators are compensated for variable generation costs, and – according to § 13a para. 2 sentence 2 no. 2 EnWG – they also receive a partial compensation for asset depreciation, referred to as the "Werteverbrauch".

For understandable reasons, the scope of this asset depreciation compensation is not publicly disclosed, which makes it difficult to assess the strength of the incentive. However, Schleich (2022, p. 5), in his explanation of the so-called "new-build advance", notes: "The Werteverbrauch compensation significantly contributes to covering fixed costs [...]" Even if the magnitude of the incentive is not precisely known, the direction of the incentive is clear: The Werteverbrauch compensation within redispatch constitutes opportunity costs compared to selling electricity on the wholesale market. These opportunity costs are marginal-cost relevant and are therefore factored into market bids.[74]

If a power plant receives remuneration for variable costs plus a share of fixed costs (through the Werteverbrauch component) when dispatched for redispatch, it will only be willing to participate in the wholesale electricity market if it can earn at least the same amount there.

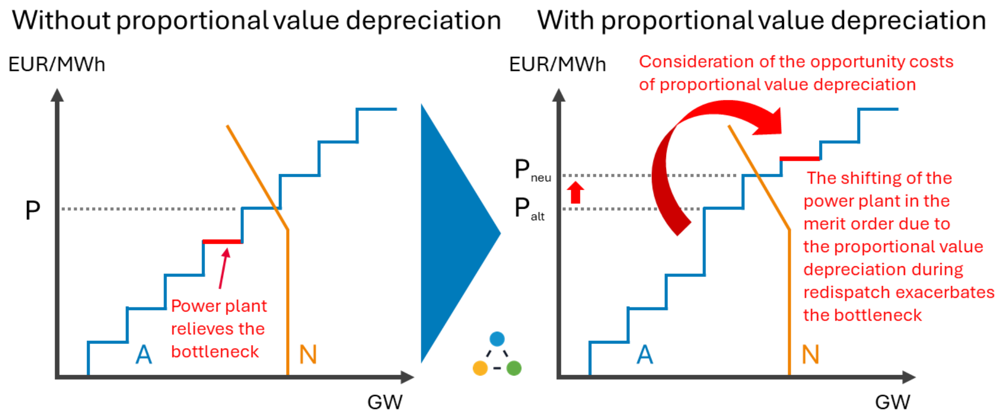
[73] The primary strategy for addressing grid congestion should be the rapid expansion of the grid. The measures discussed here are intended solely to provide system-friendly incentives during the transitional phase until grid expansion is complete.

[74] This is consistent with market-based behaviour and was, for example, extensively discussed in the context of the pricing of freely allocated $CO_2$ certificates.

Typically, power plants only bid their variable costs into the market. Their fixed costs are recovered through producer surplus – that is, by earning higher prices when more expensive plants set the market-clearing price. This bidding behaviour is economically rational: even if fixed costs are only partially covered, the plant still operates, contributing to market efficiency.[75]

However, if a power plant expects to be partially compensated for fixed costs through redispatch payments, these expected revenues influence its market bid. Specifically, the plant increases its offer price, incorporating the opportunity cost of missing redispatch remuneration. As a result, the plant moves upward in the merit order, making it less likely to be dispatched under normal market conditions – potentially leading to higher electricity prices (see Figure 32).

*Figure 32: Bidding Behaviour With and Without Consideration of Opportunity Costs Due to Pro Rata Value Depreciation*




*Source: Own illustration.*

If the power plant is not dispatched due to factoring a portion of its fixed costs into its bid, it may ultimately exacerbate grid congestion. This is particularly relevant for plants located in grid-constrained areas where redispatch capacity is most often required. These plants internalise the opportunity cost of lost redispatch revenues – especially the Werteverbrauch – into their market bids.

This bidding behaviour is often referred to as "inc-dec gaming". However, it simply reflects the economic reality that opportunity costs are taken into account when forming a bid. From a business perspective, this is a rational and incentive-consistent strategy.

From a systemic perspective, however, this constitutes a classic misaligned incentive. It particularly affects power plants that would be highly beneficial for

[75] The economic incentives are explained by the peak-load pricing model (see Section 4.1).

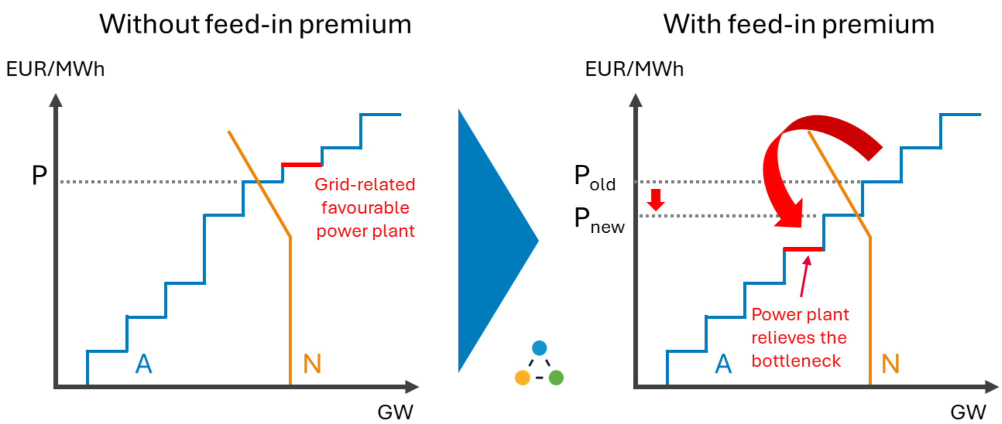
relieving network congestion if dispatched through the market. The example clearly illustrates why it is crucial to design market mechanisms that promote system-friendly incentives and to avoid distortionary effects that lead to increased system costs.

The identification of opportunity costs is not always straightforward, but their incentive effect has real consequences for market behaviour and system security. In the case at hand, the misaligned incentive tends to amplify grid congestion and increase the need for redispatch measures.

From the perspective of system-compatible incentives, it would be more effective to internalise positive externalities, rather than to reinforce the problem of non-internalisation through redispatch compensation mechanisms. Just as negative externalities can be priced to enhance welfare, positive externalities can be rewarded through targeted premiums, leading to welfare gains. If a power plant contributes a positive external effect by injecting electricity at a grid-beneficial location, this effect can be incentivised economically via a feed-in premium.[76]

Such a premium would have the opposite effect of the redispatch-related partial fixed cost compensation. Specifically, it would lower the plant's bid price, thereby increasing the likelihood that it is dispatched even at lower market prices, thus relieving congestion (see Figure 33).

*Figure 33: Congestion-Relieving Shift of the Power Plant in the Merit Order Due to a Feed-In Premium*




*Source: Own illustration.*

As illustrated in Figure 33, power plants located at grid-beneficial sites that receive a feed-in premium would be dispatched more frequently on the

[76] In this context, the positive externality may relate to various system services.

electricity market. As a result, grid congestions would be mitigated more often – and in some cases, perhaps even entirely avoided. On the downside, however, the premium would lower wholesale market prices, thereby introducing a new market distortion.

The current redispatch regime tends to exacerbate grid congestion and elevate market prices, whereas the feed-in premium would generally alleviate congestion and suppress price levels.

Yet, the underlying issue remains the limited grid capacity. Therefore, a swift and comprehensive expansion of the electricity grid is the only sustainable solution within the framework of a single bidding zone.

The exact design of the remuneration level requires a more in-depth analysis, not least because the magnitude of external effects varies depending on the specific situation.[77] Therefore, the premium should also be adjusted situationally, reflecting the respective positive system effect. It should be determined prior to the day-ahead market, with the current partial fixed cost compensation for asset depreciation in the redispatch process serving as a reference point for the lower bound. As a benchmark for the upper bound, the costs of alternative redispatch measures could be considered.

The use of feed-in premiums at grid-beneficial locations can also create incentives for system-friendly investment – especially in combination with the measures discussed in Section 6.2 However, these premiums are not investment subsidies, but rather an element of market design. This means the premium is discontinued once the system benefit ceases to exist. Depending on the type of system service provided, this could mean, for instance, that some power plants lose eligibility once grid expansion is completed. This design creates a timely incentive to invest early in capacity at system-relevant locations to benefit from the premium. By contrast, subsidies would continue to be paid even when no further system benefit is delivered, leading to inefficient outcomes.

Even within this approach, it remains essential that network operators retain access to ultima ratio instruments – such as redispatch and the capacity reserve – to ensure secure system operation. The introduction of a feed-in premium can reduce the frequency and scope of redispatch measures, whereas the current regulation tends to increase both the extent and frequency of redispatch interventions.

[77] In addition, state aid approval for measures within bidding zones is a relevant aspect. As a point of reference, the concept of 'proportional value consumption' granted under the current redispatch regime could be used. If the current redispatch regulation remains in place, the incentive effect of the feed-in premium should at least offset the existing disincentive.

## 6.2 A MARKET-BASED INCENTIVE SYSTEM TO ENSURE SECURITY OF SUPPLY

When selecting appropriate market design adjustments, it is crucial to address the actual problem in a targeted and effective way. The growing number of generation and consumption units, each with decentralised information and individual usage preferences, increases the complexity of the overall system. In this context, especially during the transformation phase and for the long-term organisation of security of supply in a system increasingly dominated by renewable energy sources, the design of an effective incentive system becomes essential.

Market actors are best positioned to aggregate and manage decentralised information regarding consumption preferences, flexibility potentials, and generation options.

Ensuring security of supply in such a dynamic system requires an antifragile approach. Antifragility emerges when the regulatory framework enables and encourages rapid learning and swift responses to evolving information. Through ongoing learning in a dynamic market environment, actors build and strengthen system resilience over time.

The hedging model meets these requirements by offering the following characteristics, which we will explore in more detail throughout this section. The hedging model:

- reduces relevant imperfections in the electricity market that have so far required regulatory intervention.
- enables the broadest solution space for improving security of supply, increasing flexibility, and fostering innovation.
- integrates the cost-efficiency of renewable energy and security of supply into a single incentive framework, resulting in lower overall system costs compared to fully subsidised systems.
- is the most robust and attractive option from a political-economic perspective, as it reduces the need for subsidies, relieves pressure on the public budget, avoids levies, and can be implemented quickly without requiring state aid approval.

In this section, we examine the benefits of the hedging model for managing the energy transition and ensuring long-term, market-based security of supply. We begin by outlining why centralised approaches are ill-suited to effectively address the uncertainties and complexities of the transformation.

### Centralised Approaches Are Not Suitable for Organising the Transformation

The defining feature of centralised approaches is that key design elements are determined administratively and thus removed from the market-based allocation process. These specifications inevitably include the required volume of technologies and, through product definitions and procurement processes, their technological characteristics as well.

The appeal of centralised approaches lies in the illusion of control: they justify their parameters using complex methodologies and seemingly unavoidable necessities. However, on closer inspection, both the justifications and the underlying methodological assumptions fail to withstand critical scrutiny.

The justification for centralised approaches is frequently based on perceived market imperfections. However, apart from the previously discussed free-rider problem, these imperfections can largely be traced back to politically induced distortions and uncertainties. Rather than preserving these distortions and responding to them with costly capacity mechanisms – which in turn create new inefficiencies – we recommend designing targeted framework conditions that directly incentivise the desired behaviour. The following summary outlines the key disadvantages of centralised approaches:

- ADMINISTRATIVE SPECIFICATIONS: The total quantity and specific technological attributes of required assets are centrally defined through planning instruments, rather than being determined via market-based allocation mechanisms that reflect consumer preferences.
- PATH DEPENDENCIES: The separation of energy and capacity price signals – combined with political incentives for overcapacity – leads to an artificial suppression of price signals. This reduces revenues for dispatchable assets and flexibility options, subsequently lowering the market value of renewable energy. The resulting distorted price signals create a long-term dependency on subsidies for both dispatchable and renewable capacities.
- TOTAL SYSTEM COSTS: Technological specifications limit the solution space and distort price signals. This hinders innovation and leads to a continuous increase in overall system costs due to suboptimal investment pathways.
- POLITICAL INTERFERENCE: The multitude of design parameters invites political influence, embedding moral hazard elements into the system and socialising risks that should be borne by companies.
- DISTORTED POLITICAL-ECONOMIC INCENTIVES: Shifting allocative decisions into the political domain disrupts price-driven feedback loops and prevents the market from moving toward equilibrium.

- MARKET FORECLOSURE: The use of derating factors based on administratively modelled assumptions reduces competitive pressure. Flexibility options and cross-border competition within the internal market are systematically disadvantaged by explicit or implicit modelling assumptions.
- FINANCING REQUIREMENTS: The additional costs of centralised mechanisms require funding through the federal budget or levies on electricity prices. This raises distributional issues (e.g. among consumer groups), potentially fuelling political conflict.

Centralised approaches are not well suited to managing complex and dynamic developments that involve a high level of technological innovation. In decentralised or market-based systems, market participants are able to aggregate a wide range of decentralised information and make use of appropriate solutions from a broad technological spectrum.

### Targeted Removal of Market Imperfections and Harnessing Innovation

The objective of electricity market design is to ensure security of supply at the lowest possible cost. This can be achieved by exposing all market participants to targeted and efficient incentives. Existing market imperfections are gradually being addressed through recent developments. This creates an opportunity to design an incentive system capable of managing the complexity of a decentralised system in a market-oriented way – while ensuring security of supply that reflects consumer preferences and remains cost-efficient.

The economically legitimate justification for state intervention lies in the current limitations on demand elasticity. However, this argument will become increasingly obsolete in the coming years, for example due to the following developments:

- The decarbonisation of the mobility and heating sectors is driving the adoption of flexible consumption technologies (including electric vehicles, heat pumps and battery storage), which together provide significant capacity and allow large volumes of energy to be shifted over time.
- The smart meter rollout provides consumers with information about their electricity consumption and associated costs.
- The widespread deployment of recent innovations (e.g. battery storage and controllable demand devices) enables consumers to respond flexibly to their individual preferences.

- From a market design perspective, the uptake of dynamic tariffs is the central component, as it aligns private incentives with overall societal welfare.

It is sometimes argued that household customers are not interested in engaging with their electricity consumption or with price signals. However, this view is rooted in the framework conditions of the past and does not look ahead. In the future, both the information and the technological tools will be in place to allow consumers to act on their individual preferences. Whether a consumer chooses to use these tools – e.g. to reduce energy costs or to decarbonise their own electricity use – should not be pre-empted by state assumptions about people's preferences.

If consumers choose to ignore the available information and price signals, that is entirely their right. After all, no one is obliged to check the price tags when shopping at the supermarket. But citizens should have the choice of how to organise their consumption. This is particularly important when the alternative – namely, state intervention – comes with significant additional costs that will ultimately also be borne by society.

For a market-based system to function effectively, it is essential that the relevant information and incentives are available to those actors who are in a position to respond appropriately:

- INFORMATION: In future, consumers will receive information on the system status, the carbon intensity of electricity generation, renewable generation levels and electricity prices via smart meters and associated apps. Suppliers will gain insights into consumer preferences – particularly consumption patterns and individual price elasticities.
- INCENTIVES: Consumers will understand how their behaviour affects their electricity costs and, for example, their carbon footprint – and how they can actively influence both. Suppliers will be able to respond to consumer preferences with tailored products and use the information to support their long-term hedging strategies.

Privately available information and incentives have the potential to significantly reduce total system costs and thereby increase overall social welfare. Importantly, welfare gains are not limited to monetary factors – the fulfilment of non-monetary preferences also plays a key role.

However, when policymakers pre-empt allocation decisions and impose additional costs on society and the economy based on those decisions, they not only risk undermining public acceptance of the energy transition – they may also jeopardise social cohesion.[78]

It is difficult for people to imagine different incentive structures or system conditions. But when the available information and incentives change, behaviour tends to shift accordingly. The following case study illustrates, by way of example, how incentive systems can shape behaviour and drive different outcomes.

### CASE STUDY: BEHAVIOURAL CHANGES THROUGH INFORMATION AND OBJECTIVE-ALIGNED INCENTIVES

Centralised approaches rely on explicit and implicit assumptions about individual behaviour. These assumptions are necessary in order to define technological properties (e.g. via derating factors) and estimate the required overall capacity. In most system models, demand is assumed to be fixed and must be met by the system. In some cases, additional assumptions about flexibility options allow for limited demand shifting. A central modelling assumption is that individual behaviour is exogenously defined. Implicitly, this means assuming that consumers face a flat electricity price of x cents/kWh for all 8,760 hours of the year, and that electricity consumption is price-inelastic. We refer to this incentive situation as Case 1.

If the consumer owns a home battery, system models usually assume that battery dispatch is optimised independently of the household's own consumption – purely based on electricity market prices.[79] This implies the existence of a dynamic electricity tariff that incentivises system-friendly battery usage. System models are typically based on the assumption of cost minimisation. Based on these assumptions, the most recent UK capacity auction, for example, assigned a derating factor of 7.74% to a 1-hour battery.

In reality, a consumer with a battery and a dynamic electricity tariff is exposed to a different incentive structure – Case 2. Dynamic tariffs and battery systems can encourage different patterns of behaviour. How a person responds to these incentives will vary depending on their individual preferences. The following

[78] A recurring pattern of social tension can often be observed: some people follow the logic of perceived necessity, while others favour alternative approaches to achieving the same goal. The first group accuses the second of lacking commitment to the goal and tends to argue from a moral standpoint. In turn, the second group feels misunderstood and prematurely judged, which leads to defensive justifications and counteraccusations. Instead of reaching a shared understanding of the common objective and discussing the most effective paths to achieve it, the well-intentioned become divided. This unnecessary polarisation typically benefits more extreme positions, thereby putting the achievement of the goal itself at risk.

[79] In detail, home storage systems are often modelled differently from large-scale battery storage. The representation at this point serves illustrative purposes only.

comparison between a fixed electricity tariff (Case 1) and a dynamic tariff (Case 2) is intended to illustrate how incentives can influence behaviour. The effects may differ in practice, depending on personal preferences.

- CASE 1: A person has a home battery and a fixed tariff that charges the same price per kWh every hour of the year. In this case, the battery may already be empty by the time the person reaches the evening – a moment with the highest electricity prices of the year and the greatest system stress. They realise they want to wash their favourite shirt and start the washing machine. At the same time, they prepare a rich dinner, bake bread in the oven, and boil water for tea. Because they like it cosy, they put on comfortable clothes and turn up the heating (via a heat pump). They may also plug in their car to charge. This example illustrates how arbitrary and welfare-reducing a fixed tariff can be. It encourages the same behaviour regardless of the system condition – even though the wholesale price might spike to €2,000/MWh in this situation, while just hours earlier, it may have been at -€150/MWh in the early morning.
- CASE 2: A person with a home battery and access to price signals may behave quite differently – especially with access to a multi-day price forecast. Perhaps they consider saving the stored energy for later (as described in prospect theory). They decide to wear their second-favourite shirt instead. Since they don't really need to use their car in the next few days, they postpone charging it. Rather than turning up the heating (via the heat pump), they put on a warm jumper. And instead of cooking and baking, they opt for a simple dinner – perhaps just some cheese sandwiches – and drink a glass of water instead of making tea.

In this case, the battery is not merely a technology that facilitates the same behaviour under otherwise equal conditions (as often assumed in models). The individual described here is exposed to a fundamentally different incentive structure. They have access to price signals and know they can benefit from more mindful electricity consumption. A 2-hour battery is defined by the ratio between its storage capacity and power output. However, under frugal usage, the same battery may cover household electricity needs for a significantly longer period. Awareness of both the state of charge and prevailing electricity prices creates incentives to adjust behaviour. Depending on personal preferences, this change may not be perceived as a burden at all – the individual may actually take satisfaction in saving money or contributing to environmental goals.

This does not imply that all consumers will behave this way. Rather, it shows that fixed modelling assumptions often fail to reflect the fact that, with modern technological infrastructure and access to information, different incentives come into play. These incentives can not only lead to a temporal shift in electricity consumption but also to a more efficient and conscious use of electricity overall. For example, the TEMPO tariff in France has led to consumers using 10% less electricity overall compared to a control group – in addition to a 23% reduction in peak demand during high-price periods (EDF, 2024b).

When derating factors are determined through centralised specifications, and a technology is displaced based on the incorrect assumption that new framework conditions do not lead to changed incentives, welfare is diminished. In the worst-case scenario, this could lead to the construction of expensive power plants that burn costly hydrogen – hydrogen which is heavily subsidised through $H_2$-CfDs. As a result, no scarcity signal is sent, and no system-oriented incentive can emerge.

The decentralised preferences of consumers cannot structurally be captured through central planning approaches. They can only be orchestrated via incentive systems. Welfare increases not only because overall system costs are reduced, but also because individual preferences can be taken into account – rather than being overridden by implicit state assumptions about consumer behaviour. In this way, integrated price signals can create targeted incentives, and the need to distribute costs through the federal budget, special support schemes, or surcharges is eliminated.

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The technological opportunities available today make it possible to overcome the market imperfections of the past. Instead of relying on central assumptions, individual preferences can now be reflected through price-elastic consumption behaviour.

### Eliminating Distorted Incentives Through the Hedging Model

As discussed in Section 5.6, certain market phases and the competitive pressure from discount suppliers can create a distorted incentive for free-riding behaviour, where suppliers forego sound risk management and fail to fully hedge their contracted deliveries on the long-term markets.[80] This leads to a lower overall demand for long-term hedging products, which in turn results in incomplete price signals. These incomplete prices represent an externality, as the associated societal risk costs are not sufficiently internalised. As a result,

[80] We define long-term markets as all market segments capable of providing hedging against market risks. This includes, among others, exchange-based trading and bilateral trading of hedging products, as well as self-generation and demand-side flexibility.

generators receive lower revenues, which can reduce the willingness to invest in peaking power plants.

This is where the hedging obligation comes into play. It aims to internalise the societal risk costs by preventing free-rider behaviour and thereby establishing a more complete price signal in the long-term markets. However, in order to avoid unnecessarily increasing the cost of hedging, suppliers should be given the option to use not only conventional energy-based contracts but also e.g. options products for risk management.

Instead of creating an additional market segment through capacity mechanisms – which would require ongoing subsidies for dispatchable capacity and renewable energy – a more complete market and price signal can be achieved through the hedging obligation. In this context, consumer preferences play a key role, as their demand for supply security can be directly revealed. The following table shows the different capacity volumes and tariffs under EDF's French TEMPO tariff.

*Figure 34: Service Options and Tariff Structure in EDF's TEMPO Tariff*

| Tempo-Options (incl. tax) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Contracted load (kVA) | Monthly subscription (€ inkl. tax) | Price per kWh | | | | | |
| | | Blue HC | Blue HP | White HC | White HP | Red HC | Red HP |
| 6 | 12,96 | 12,96 | 16,09 | 14,86 | 18,94 | 15,68 | 75,62 |
| 9 | 16,16 | 12,96 | 16,09 | 14,86 | 18,94 | 15,68 | 75,62 |
| 12 | 19,44 | 12,96 | 16,09 | 14,86 | 18,94 | 15,68 | 75,62 |
| 15 | 22,45 | 12,96 | 16,09 | 14,86 | 18,94 | 15,68 | 75,62 |

*Source: EDF (2024a).*

The first column of the table shows the capacity for which customers can conclude a supply contract.[81] As previously discussed, the rollout of smart meters lays the foundation for electricity to become a private good. By enabling both rivalry in consumption and excludability, electricity can, in principle, be governed by the standard market-based rules of private goods. However, we have also pointed out that a basic supply of electricity can generate positive externalities, which provides an argument that securing a minimum level of supply may have a welfare-enhancing effect.

[81] To convert to kW, it is necessary to apply a power factor to the value given in kVA. Power factors for consumer installations typically range between 0.9 and 1.0. For a conservative estimate in the case of a household connection, a power factor of 0.9 can therefore be assumed.

Section 14a of the German Energy Industry Act (EnWG) stipulates that distribution system operators may reduce electricity supply to 4.2 kW during network congestion in order to prevent overloads. In principle, this logic of limited network capacity can also be applied to limited generation capacity. If a customer wishes to secure, for example, 8 kW of electricity supply, the supplier can hedge this amount on the long-term markets. For the decision-making process, the supplier can provide the customer with statistical analyses of their historical consumption behaviour.

If a consumer wishes to use more electricity in a given situation, there is generally nothing to prevent this, provided that sufficient generation capacity is available. If no generation capacity is available, or if the price exceeds a threshold previously agreed upon with the consumer, then – similar to network congestion under Section 14a EnWG – the consumer can be throttled down to their secured capacity. The consumer should therefore bear the price risk for any additional consumption (see, for example, Neon, 2023b) and be subject to curtailment if necessary. This reflects the typical handling of non-storable goods.

If someone wants to travel by plane, they can go to the airport and pay the current fare. In the case of a limited number of seats, the ticket price can be very high at short notice – just like electricity prices can spike on the spot market. However, the customer also has the option to book the flight in advance and secure a lower fare. This approach is equivalent to hedging electricity prices on the long-term markets.

When it comes to air travel, customers also have the option to book travel cancellation insurance. This effectively turns the booked flight into an option: if the customer decides to travel, the full cost applies; if they cancel the trip, they only pay the insurance premium. This is essentially equivalent to complementing electricity long-term markets with options products. Market participants in the electricity sector already have experience with such options transactions – whether through bilateral hedging contracts for power plant outages, investments in power plant shares, or participation in EEX cap futures.

THROUGH THE HEDGING OBLIGATION, RISK EXTERNALITIES ARE INTERNALISED, RESULTING IN A MORE COMPLETE PRICE SIGNAL THAT CAN INCENTIVISE NEW INVESTMENTS IF NEEDED.

The hedging obligation in the electricity market is necessary to eliminate the free-rider incentive that can lead to negative external costs for society by resulting in an insufficient level of capacity being secured. If flights are fully booked for a short-notice trip, the individual customer simply misses out. In contrast, customers of an insolvent electricity discounter are taken on by the basic supply service. Due to this difference, a hedging obligation in the electricity market – unlike in other non-storable product markets – is in the public interest.

For consumers, it makes no difference whether curtailment occurs due to limited grid capacity, constrained primary energy supply, or a shortage of generation capacity. If they are not willing to pay for an uninterrupted electricity supply, then in the event of scarcity, they will be limited to the level of capacity contractually agreed upon.

At this point, however, social factors also come into play. Vulnerable customers can be protected through the crisis mechanism (see discussion in Section 6.1.1). For example, if a low-income customer lives in a region with limited grid capacity, the financial burden from constrained transmission infrastructure may be comparable to a shortage of primary energy. In such cases, the mechanism could be extended to cover high grid-related cost burdens as well. This would allow system-friendly incentives to remain effective, while the financial strain is cushioned through the transfer mechanism.

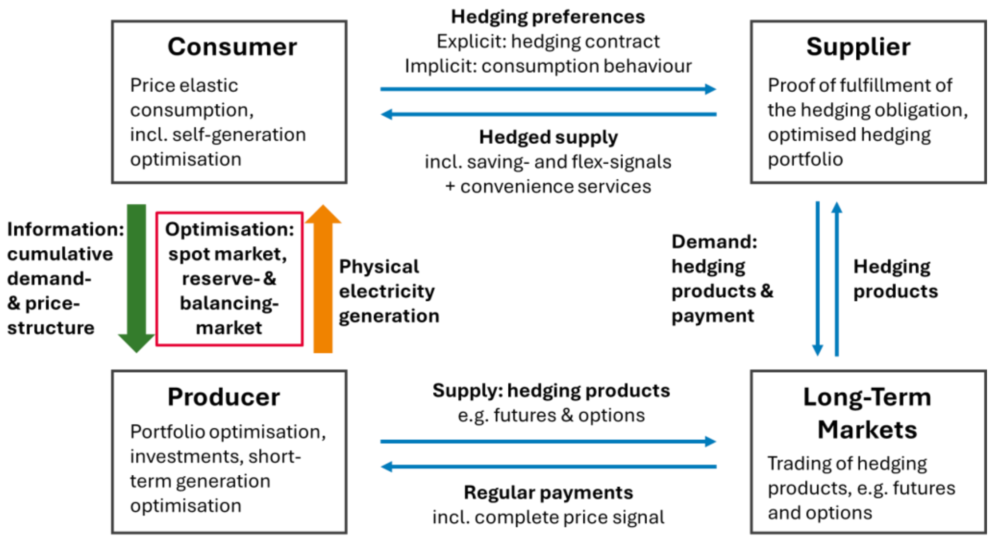
The key advantage of the hedging obligation – and thus the integrated pricing of energy and capacity – is the creation of an antifragile system. As all market participants continuously learn to respond to price signals, the flexible consumption behaviour that has been trained over time can also be activated in times of crisis. Consumers learn to recognise when their electricity use is particularly costly. By visualising their load profiles and receiving statistical evaluations, they also gain a better understanding of their own consumption patterns. Based on this, they can book hedging volumes and behave in a system-friendly manner beyond that. As NEON (2023b) demonstrates, consumers can also benefit financially from reducing their consumption during periods of high market prices.

PRICE-ELASTIC CONSUMERS NOT ONLY REDUCE THEIR OWN ELECTRICITY BILLS, BUT ALSO LOWER THE ELECTRICITY BILLS OF OTHER CONSUMERS BY REDUCING OVERALL SYSTEM COSTS.

Suppliers can offer a wide range of product features. Sales teams therefore have many opportunities to differentiate their products, including through the integration of complementary services. As a result, the expansion of dynamic tariffs can benefit from the high level of competition in the German retail market. There are already dynamic tariff offerings that integrate smart infrastructure, including heat pumps, solar PV systems, home batteries, and electric vehicles.

To illustrate the hedging obligation, Figure 35 presents the interactions between market participants and trading venues.

*Figure 35: Interactions Between the Actors and Marketplaces in the Implementation of the Hedging Obligation*




*Source: Own illustration.*

Consumers can hedge their preferred capacity level with their supplier, who in turn procures the corresponding volume on the long-term markets. However, suppliers may also take their customers' price-elastic behaviour into account when designing their procurement strategies, and therefore procure additional capacity. For example, suppliers can differentiate between comfort-oriented and cost-conscious product options.

Producers offer the corresponding hedging products on the long-term markets. Based on the demand observed on the long-term markets – combined with more complete price signals – they gain crucial information for portfolio optimisation. Additionally, they receive valuable real-time information from the aggregated demand structure and price signals on the short-term markets (green arrow), which further supports portfolio optimisation. Persistent high-price periods may incentivise investment in (hydrogen-based) gas power plants, whereas shorter demand peaks may favour investments in storage technologies. Suppliers and vertically integrated companies can also explore further opportunities for demand flexibility in partnership with their customers.

Depending on individual preferences, electricity consumption can either be controlled automatically or manually by the consumer. For reasons of public acceptance, maintaining consumer choice should always be a priority. For instance, in addition to price signals, suppliers may send system messages to encourage behavioural adjustments – i.e. to "nudge" consumers – or directly manage devices in order to provide system services, for example as part of a virtual power plant.

Bonus schemes can also support the learning process for price-responsive consumption behaviour. By applying elements of gamification[82], such programmes can increase motivation while simultaneously strengthening customer loyalty.

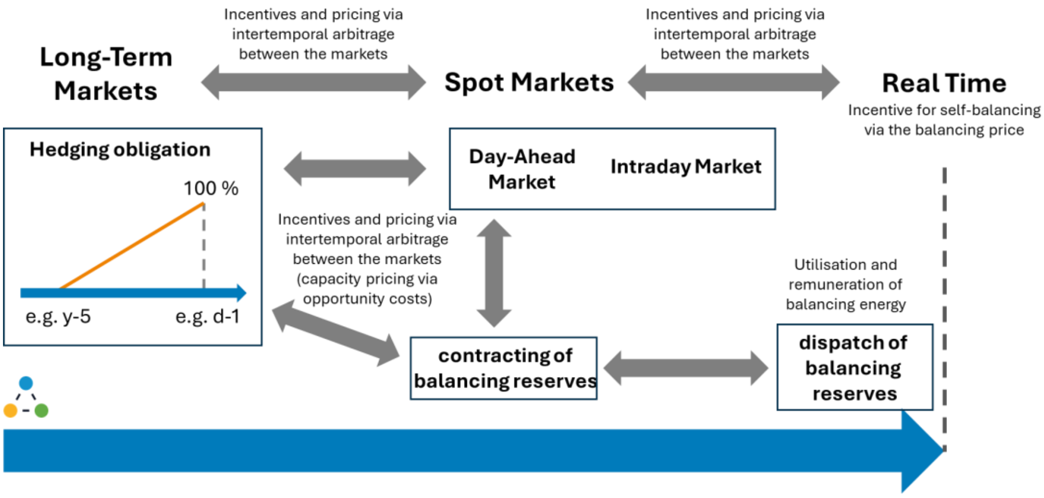
This type of market-based organisation of security of supply was already proposed by BDEW (2014). Since then, however, technological capabilities have progressed significantly – meaning that even fewer regulatory prescriptions are required to establish an incentive-compatible system. BDEW (2014, p. 6) states: "One key feature of the decentralised capacity market is that no government regulator centrally determines the required secured generation capacity in a planned economy fashion, nor are the associated costs distributed independently of the originator. Instead, the total secured capacity to be maintained is defined by the actual demand of electricity consumers and financed in line with the polluter-pays principle. Moreover, the DLM grants wide flexibility for the integration of demand-side flexibility, which can reduce consumers' capacity needs during scarcity situations, making it particularly effective in tapping into DSM potential."

The hedging obligation goes a step further: it offers a way to address two major market imperfections – inelastic consumer demand and free-rider incentives – at their root. As a result, it avoids the slippery slope toward a central capacity market. No additional capacity guarantees are required. The hedging obligation simply requires a system to verify the contracted hedges. With today's technological capabilities, this verification can be implemented with relatively little effort through digital solutions.[83] Figure 36 illustrates the role of the hedging obligation within the market framework.

[82] Gamification refers to the use of game-like elements and principles in non-game contexts. Many mobile apps, for example, rely on these principles to increase user motivation for behavioural change through rewards, tips, and challenges. Some people are motivated by saving money, while others respond more strongly to reducing $CO_2$-emissions or increasing the share of renewable energy. Still others are more responsive to abstract games, such as feeding a 'Tamagotchi' or building a virtual farm. End-customer competition enables these individual preferences to be addressed accordingly.

[83] For instance, a consumption portfolio could be evaluated by comparing the aggregated individual load profiles and the peak loads hedged by suppliers against the sum of the dedicated capacities, hedging contracts, and option-based hedges. Any shortfalls could be flagged through corresponding signals. A mandatory tracking log could record when and to what extent such shortfalls occur. In theory, aggregated reporting (e.g. in the form of traffic light indicators or percentages) could be transmitted automatically to a regulatory body to demonstrate compliance. In addition to the deterrent effect of penalties, such a system could also help detect abusive behaviour, which – depending on the severity and intent – could even have legal consequences.

*Figure 36: Illustration of the Hedging Obligation in the Market Structure*[84]




*Source: Own illustration.*

Due to the (intertemporal) arbitrage opportunities[85] between the various market segments, a comprehensive incentive system emerges that enables investors to make well-informed investment decisions. On the long-term markets, for example, futures and options products are in an arbitrage relationship: when the supply of one product becomes scarcer, the price structure of the other adjusts accordingly.

To ensure the effectiveness of the hedging obligation, it is necessary to define a starting point for the procurement period. Cramton et al. (2024) propose that the hedging obligation should begin four years ahead of the delivery period, starting at zero per cent and then increasing linearly over time. Wolak (2021), by contrast, proposes a five-year lead time before the delivery period begins.

The mandatory hedging of expected peak loads leads to more complete prices in the long-term markets through intertemporal arbitrage. As a result, suppliers are incentivised to conclude hedging contracts well in advance – much like booking a flight early to secure a lower price. For producers, the incentive lies in receiving long-term remuneration for electricity generation or available capacity. As in all market-based transactions, the decisive factor in price formation is the expectation of future market developments.

[84] In the balancing reserve, there is indeed a capacity-based remuneration for the provision of different reserve products. However, this 'capacity payment' is not based on the fixed costs of the contracted assets, but rather on the opportunity costs of foregone revenues from other market segments.

[85] Arbitrage refers to the alignment of prices across interconnected markets through trading activities. When the price in one market segment is lower than in another, demand increases in the cheaper segment until prices converge. In this way, arbitrage strengthens the robustness of price signals, providing investors with a more reliable basis for investment decisions.

In order to ensure compliance with the hedging obligation, a penalty mechanism is nevertheless required. This penalty should be set at a sufficiently high level to make any form of "gaming" economically unattractive. BDEW (2014) proposes the use of a multiple as a basis for design. For example, a shortfall in the hedged quantity could be penalised at four times the hedging price at the time of the shortfall.

Beyond this, it is likely that no additional penalty add-on will be needed within the balancing group system if the consumption exceeds the hedged volume secured via the long-term markets due to additional short-term demand.[86] The existing balancing system already incentivises balanced portfolios and, through intertemporal arbitrage logic, sends appropriate price signals to the spot and long-term markets. Any additional costs incurred from excess consumption are simply allocated to the respective consumers by the supplier – thereby enabling the system to deliver appropriate incentive effects.

### Market Actors Find the Suitable Solutions

The hedging obligation offers the greatest possible technological openness. Suppliers identify the need for hedging based on the preferences and characteristics of their customers. On the consumer side, there are numerous opportunities to optimise costs. Industrial consumers in particular can decide how much of their demand they want to hedge on the long-term markets and explore ways to increase their flexibility or reduce their consumption through efficiency measures.

Producers can use a portfolio of different technologies to offer both energy and option products. When long-term market prices signal scarcity, they can benefit from these higher prices and invest in a broad range of generation technologies and flexibility options.

Suppliers can be creative in their product design and offer lower prices if they are able to leverage demand-side flexibility options for optimisation. There are already products on the market that, for example, combine car batteries or home storage systems with controllable consumption devices to form virtual power plants that also provide ancillary services. These products take consumer preferences into account, reduce their costs, and create a significant welfare effect. However, they could hardly be integrated into regulated capacity products, which means that such innovative approaches would be crowded out

[86] Even if there is currently no need for action, the incentive system should nevertheless be reviewed on an ongoing basis in order to identify and correct any incentive gaps if necessary.

by capacity markets. In contrast, they are well suited to a market-based hedging obligation.

The key advantage of the hedging obligation is its openness to innovation. By definition, innovations are unknown in advance. It is therefore not possible to design regulatory capacity products that can account for the yet-unknown characteristics of future technologies. In the hedging obligation model, however, they can be integrated without difficulty – either on the supply side as part of a portfolio, or on the demand side to increase one's own hedging and flexibility. When integrating technological innovations, only the added value matters for market success – not whether regulators are willing to adjust product definitions, which could also disadvantage existing technologies. Instead of political decisions, market actors can choose the technologies that best fit their needs.

In combination with the adjustments discussed in Section 6.1.2, products can also incorporate regional characteristics. For example, they can aim to maximise the consumption of locally generated renewable energy or deliver substantial systemic value by taking dynamic network charges into account. Where appropriate, local investments can also be incentivised to enhance the value proposition for local customers – without the need to break up the uniform bidding zone.

### Integrated Incentive System for Ensuring Security of Supply and Integrating Renewable Energy

The hedging obligation inherently incentivises demand-side flexibility. In this context, self-generation can also be taken into account in a system-supportive way.[87] Industrial consumers, in particular, can leverage flexibility to achieve multiple effects simultaneously: for example, increasing their share of renewable energy – via self-generation or PPAs – while at the same time reducing their hedging requirements.

From a system-wide perspective, the hedging obligation creates an integrated incentive system that enables a cost-efficient approach to ensuring security of supply while promoting the integration of renewable energy sources. As a result, support costs for renewables can be reduced on a lasting basis.

In contrast, capacity markets tend to weaken long-term revenue opportunities for both dispatchable capacity and renewables in the wholesale market, thereby

[87] In EDF's Tempo tariff, for example, there is a component of €8.88 per month, which is presumably used to compensate for network costs (EDF, 2024a).

creating a permanent need for subsidies across both segments. Over time, the resulting path dependencies and reduced competition lead to structurally higher total system costs.

Under the hedging obligation, new products and services are likely to emerge that provide all relevant information to all consumer groups – often via apps – in order to reflect their specific preferences. These may include data on renewable energy feed-in, the carbon intensity of electricity generation, the system load in relation to the contracted hedging level, and current prices, including dynamic network charges.

By integrating relevant information and targeted incentives, all elements of the system can be brought together into a welfare-enhancing incentive framework. Instead of financing externalities through an ever-growing number of subsidy schemes, the internalisation of relevant external effects generates more complete price signals – motivating all actors to behave in ways that support the overall system.

### A Political-Economically Robust System

Policymakers typically have a preference for additional safeguards. In this context, the existing capacity reserve serves as an ideal complement to prepare for unforeseen developments. However, to ensure compatibility with the hedging obligation, it is essential that the capacity reserve continues to be deployed exclusively outside the market.

There are occasional proposals to activate it – like other strategic reserves – at lower market prices. However, doing so would undermine the incentive to hedge, lead to a gradual expansion of the reserve, and create uncertainty about the future market design. In its current form, the reserve is the best possible complement to the hedging obligation. Like the proposed social crisis protection mechanisms, it helps to pre-empt future debates about changes to the market design. After all, the stability of regulatory conditions is crucial for a favourable investment climate.

In summary, the integration of the proposed developments outlined in this study results in a consistent and robust incentive system. On the one hand, all relevant scarcities are incorporated into the price-based incentive structure, creating sustainable welfare gains. On the other hand, political-economic aspects are addressed with the aim of ensuring stable framework conditions. There is no need for political debates around revenue clawbacks, de-rating factors, or distributional questions. The relevant incentives are reflected in electricity market prices, eliminating the need for additional subsidies that would burden the federal budget, require new funding schemes, or necessitate another levy.

The hedging obligation is ideally suited to integration within the internal energy market, as market participants can utilise existing cross-border trading products. Any potential new hedging products would also be compatible with cross-border trade. Moreover, the approach does not require state aid approval, since it simply implements provisions already enshrined in the European Electricity Market Directive. As such, the mechanism can be implemented more swiftly than alternative capacity mechanisms.

Overall, the hedging obligation establishes a market-based and political-economically stable incentive system that provides a reliable investment framework for the transformation of the energy system. Moreover, it is capable of integrating technological innovations in the best possible way, which gives it the potential to serve as a viable and sustainable market design well beyond the transformation period.

As previously mentioned, it is difficult for people to imagine how their perceptions shift when they find themselves in a different incentive environment. During an energy crisis, there is a widespread belief that prices will remain high in the future – often sparking debates about industrial electricity prices. Conversely, when prices are low, investors worry that they will stay low, prompting calls for subsidy schemes. An integrated and sustainable market design with more complete prices ensures that incentives are aligned with revealed consumer preferences and willingness to pay, thereby securing an adequate level of supply security at the lowest possible total system cost.

# 7 Summary and Conclusion

This study examines how security of electricity supply can continue to be ensured in the best possible way in the future. The answer to this question is currently subject to intense debate. Opinions range from strengthening the electricity market to introducing state-organised capacity markets. The study concludes that the electricity market can be further developed in a way that strengthens the market-based organisation of security of supply and incentivises the required capacity through the market itself. A well-designed implementation of the hedging obligation, as introduced in the most recent reform of the European Electricity Market Directive, provides a suitable starting point. Currently, an implementation approach to this hedging obligation is being discussed, which was presented in the "Strommarkt-Plus" concept developed by Consentec (2023) within the Platform Climate-Neutral Power System (PKNS).

From a political-economic perspective, this is also the most cost-efficient and robust measure for public authorities, with the lowest implementation effort. From a European legal standpoint, it is the ideal instrument to strengthen the internal market, offering the additional advantage of rapid implementation. The hedging obligation constitutes a further development of the current system, making it significantly easier and faster to implement than a complete and error-prone overhaul of the incentive structure.

### Do We Really Need to Subsidise Everything?

The answer to this question becomes clearer when we examine what is currently hindering the electricity market:

- DISTORTED POLITICAL-ECONOMIC INCENTIVES: From a game-theoretic perspective, the politically announced coal phase-out – "ideally" by 2030 – combined with the ongoing debate about capacity mechanisms creates a classic disincentive for investors. They are faced with a choice: either they invest now, or they wait and later receive government subsidies for doing so. This raises the question of whether entrepreneurial risks should be borne by society – despite society being ill-equipped to manage them effectively. Under these conditions, investment restraint (attentism) becomes a rational response.
- MARKET IMPERFECTIONS: Externalities resulting from market imperfections call for regulatory adjustments to ensure that price signals can unfold their full effect.

  - LIMITED PRICE ELASTICITY OF DEMAND: Until now, electricity consumers have been unable to respond to prices with sufficient elasticity to express their willingness to pay for a secure electricity supply.
  - FREE-RIDER PROBLEM: Suppliers who do not hedge their delivery obligations on the long-term markets generate a risk externality. This leads to incomplete price signals on the long-term markets, which in turn under-incentivises dispatchable capacity.
- AMBIGUITIES: There are currently several (political) uncertainties that are difficult for companies to manage. These include questions such as: Will the coal phase-out be organised through the market or by the state? Will there be future interventions in price formation? How credible is the emissions reduction path under the European Emissions Trading Scheme? How will the hydrogen market develop? What is the future of the bidding zone? These uncertainties currently dampen private investment.
- COMPLEXITY: The growing decentralisation due to new generation and consumption technologies increases the complexity of market operations. This complexity creates additional demands on market organisation. Centralised control would require constant adjustments, increasing both the uncertainty for market participants and regulatory complexity itself.

### What Are the Economic Foundations of a Market-Based Approach to Security of Supply?

The appropriate market design for the transformation phase and beyond integrates incentives for both secure electricity supply and the integration of renewable energy sources into a cost-efficient overall system.

- MARKET ORGANISATION: A market-based approach fully assumes the allocation tasks and uses price signals to orchestrate the behaviour of market participants in line with system goals. In contrast, competitive tenders shift many allocation decisions to a central entity in advance.
- COMPETITION: Only competitive markets reveal the information needed for efficient allocation. Furthermore, competition – along with the associated risks – creates the relevant incentives for market participants to develop an increasingly cost-efficient electricity system in an evolutionary way.
- MARKET-BASED INCENTIVES: In order for incentives to be effective, complete price signals are required – signals that internalise willingness

to pay and external effects so that appropriate investment decisions can be made.

- SECURITY OF SUPPLY: To ensure security of supply at the lowest possible cost, the entire value chain must be considered: energy security, generation adequacy, system adequacy, and demand flexibility. Focusing solely on generation technologies can reduce supply security if it results in technological concentration and increased systemic risks. Using a broad mix of technologies therefore strengthens security of supply.
- DYNAMIC SYSTEM ADJUSTMENT: In a dynamic system characterised by rising decentralised consumption technologies and high shares of renewables, the requirements for meeting demand change over time. Rather than maintaining peaking power plants solely for rare demand spikes, (unconventional) flexibility options can more cost-efficiently balance supply and demand. Attempting to define the right technologies through regulation increases total system costs.
- INTERNAL MARKET: Leveraging a range of technologies across the internal market strengthens supply security (portfolio effect). In addition, the geographical diversification of renewable generation and demand patterns across Europe allows for a high level of supply security with lower overall capacity requirements – ultimately reducing total system costs.
- FLEXIBLE CONSUMERS: The value of flexible consumers lies not only in their ability to shift consumption, but more importantly in the way they reveal their willingness to pay through flexible demand behaviour. In doing so, they contribute to a more cost-efficient system and send reliable investment signals to market actors.

### Why Are Selective Mechanisms and Capacity Markets Inadequate?

A power plant support scheme – and by extension, capacity markets – creates path dependencies that result in long-term subsidy needs across all system components, thereby increasing total system costs over time. The capacity mechanisms currently under discussion resemble traditional subsidy programmes more than a sustainable market design, as demonstrated by experiences with US and European capacity markets. They exacerbate existing market imperfections and hinder a market-based organisation of electricity supply.

- SELECTIVE MECHANISMS: As highlighted by current policy debates and the development of the Power Plant Strategy (KWS), selective capacity mechanisms that promote only certain technologies are vulnerable to political uncertainty and prone to political influence (rent-seeking). They displace (innovative) alternatives and distort competition – including within the internal market. Moreover, they create long-term subsidy expectations and regulatory interventions.

- CAPACITY RESERVE: The capacity reserve can safeguard supply in competitive electricity markets without distorting market signals. As their deployment is limited to situations where the market fails to clear, price incentives remain intact. A small reserve is sufficient to hedge rare and unforeseeable uncertainties.
- DECENTRALISED AND HYBRID CAPACITY MARKETS: These mechanisms tend to evolve into centralised capacity markets over time due to growing political adjustments and regulatory interventions.
- CENTRALISED CAPACITY MARKETS: Centralised mechanisms attempt to balance market power mitigation with investment incentives by relying on extensive administrative rulebooks and numerous regulatory levers.
  - Market-based allocation mechanisms are replaced by central decisions. The assumption that there is only one technical solution to address prolonged periods of low renewable generation (so-called Dunkelflaute) implies that no market-based allocation is needed. In reality, there are numerous options to address demand, all of which influence the requirement for thermal capacity. In a dynamically evolving system, administrative capacity planning based on assumptions about the future structurally leads to overcapacity and crowds out (innovative) solutions.
  - The technology-specific requirements (especially derating factors) that are needed in capacity markets to estimate the contribution of each technology to security of supply and to determine capacity payments are defined using central planning tools. As a result, administrative assumptions about the future determine the future profitability of the participating technologies. Competition in the internal market and between (innovative) technologies is distorted through the administrative determination of derating factors, e.g. for storage.
  - The product features of the capacity market (lead time, determination of derating factors, etc.) are necessarily geared towards the characteristics of thermal power plants. In combination with political-economic incentives for overcapacity, this leads to the crowding-out of flexibility options and technological innovations. This reduces the flexibility of the power market, which in turn reduces the market value of renewables and creates a long-term need for subsidies. Overall, the funding requirements for all system elements increase, which permanently raises total system costs.

- Due to bidding limits and clawback mechanisms, heavily regulated capacity markets approximate a cost-plus regulation with competitive elements. This means that revenues are set administratively rather than through market discovery. Shifting entrepreneurial risks onto the economy and society creates political-economic distortions (moral hazard) and externalities, as economically adequate risks can no longer be managed adequately.
- The multitude of parameters to be defined (capacity demand, derating factors, bid caps, clawback instruments, etc.) invites political interference (rent seeking) and ongoing discussions on regulatory changes, increasing political uncertainty for all actors in the electricity market – not just those participating in the capacity market.
- Capacity markets require funding via the federal budget or a levy. Experience from the debate on industrial electricity prices has shown that the distribution of these funds is accompanied by political disputes and disruptions in the economy and will also lead to lasting uncertainty. However, the main costs of capacity markets do not lie in the direct subsidies, but in the path dependency caused by technology displacement, which creates further long-term funding requirements. Ultimately, a capacity market generates additional externalities, creates a slippery slope for overcapacities and further interventions, and thus increases overall system costs.

Capacity support schemes are not suitable for ensuring security of supply in a dynamic electricity market with a high share of renewables. Selecting specific technologies based on today's assumptions about the future, while displacing flexibility options and innovative solutions, leads to path dependencies and permanently higher overall system costs.

Due to the previously discussed disincentive that lead to investment restraint, a decision in favour of a capacity market would likely prolong the state of wait-and-see. This is because it takes several years to implement such a system until all regulatory details become calculable for investors. It is a typical feature of misaligned incentives that, despite good intentions and a clear objective, the outcome ends up being the opposite of what was intended.

### What Framework Conditions Can Improve the Market-Based Organisation of Security of Supply?

The first step towards a sustainable market design is the development of effective framework conditions that reduce existing uncertainties and frictions so that price signals can unfold their incentive effects. This includes the following aspects:

- CRISIS MECHANISM: To relieve decision-makers in times of crisis and scarcity, a mechanism is needed that can address social and economic hardship in a targeted manner – rather than interfering with price formation and thus restricting market-based allocation mechanisms.
- INCREASING DEMAND ELASTICITY: The main benefit of elastic demand does not lie in its technical flexibility, but in the willingness to pay for a secure electricity supply. In doing so, reliable investment signals are sent. For residential customers, the smart meter rollout and the adoption of dynamic tariffs should be implemented swiftly. For larger consumers, further development of the special grid charges under § 19.2 StromNEV is advisable, taking into account the competitiveness of the companies.
- STRENGTHEN THE EMISSIONS TRADING SYSTEM: The reduction path of the European Emissions Trading System should be the primary instrument for decarbonisation. The credibility of the system should be reinforced politically so that its investment signals can take effect.
- AVOID DISTORTING $H_2$-SUPPORT: Subsidising operational hydrogen-based electricity generation – for example through $H_2$-Contracts for Difference ($H_2$-CfDs) – would displace flexibility options and other technologies. This intervention in allocation would not only permanently increase overall system costs but also weaken security of supply. It would create dependencies on a fuel whose availability and cost remain uncertain.
- ACCELERATE REALISATION TIMES: The ability to implement investments quickly increases both security of supply and economic responsiveness.
- LEVERAGE SPATIAL ALLOCATION SIGNALS: Currently, there are no spatial allocation signals within the bidding zone, creating uncertainty for investors regarding future bidding zone configurations. By internalising the external costs of scarce transmission infrastructure into price signals, grid congestion can be reduced – thereby strengthening investor confidence in the continuity of the existing bidding zone.
    - DYNAMIC INCENTIVES FOR GRID USAGE: Scarce transmission capacity across all voltage levels creates external costs. By internalising these externalities through time-dynamic incentives for

grid usage, redispatch volumes and curtailment under § 14a EnWG can be reduced. In addition, allocation via price signals enables the individual benefit of electricity consumption to be taken into account.

- CORRECT REDISPATCH DISTORTIONS: In redispatch, part of the fixed costs (so-called asset depreciation costs) is reimbursed. This cost component is factored into bidding behaviour on the power market, making it less likely for grid-friendly plants to be dispatched in the market. As a result, grid congestion is exacerbated and these plants must be redispatched later. The positive externalities of grid-advantageous assets could instead be recognised via a feed-in premium, which would allow them to be more often dispatched in the market. Such premiums would also reward timely investments in grid-supportive locations.

### Why is the Hedging Obligation Superior to Capacity Markets?

A sustainable market design corrects market imperfections and incentivises secure electricity supply through market-based mechanisms. The hedging obligation, as mandated by the European Electricity Market Directive, addresses key market imperfections at their root, thereby reinforcing the market-based organisation of security of supply. The following elements are part of the hedging obligation:

- Suppliers who do not hedge their delivery obligations on the lon-term markets create a negative risk externality, as became evident during the energy crisis through the wave of insolvencies and the associated obligation for basic suppliers to take over affected customers. This "free-rider behaviour" leads to an underhedging of long-term supply obligations on the long-term markets.
- Due to the lower level of hedging, investors have fewer incentives to invest in dispatchable capacity. A hedging obligation addresses this market imperfection. By enabling the value of security of supply to become visible through appropriate hedging products on the long-term markets, clear incentives emerge to invest in dispatchable capacity.
- Consumers can determine how much capacity they want to hedge based on their historical consumption patterns. In doing so, the second key market imperfection is resolved: consumers can signal their willingness to pay for a secure electricity supply explicitly through their hedging preferences and implicitly through their flexible consumption behaviour.

- Investors benefit from investment signals based on individual willingness to pay. This reduces the risk of a permanent regulatory spiral and lowers uncertainty surrounding unpredictable future rule changes.
- The hedging obligation provides cost-efficient incentives for the flexibilisation of the electricity system across a broad technological spectrum, thereby ensuring security of supply while enabling the efficient integration of renewable energy sources. As a result, the market value of renewables increases and subsidy costs decline. Overall, total system costs are significantly lower than under the introduction of a capacity market, which – due to price distortions – would necessitate the ongoing subsidisation of all system components.
- The hedging obligation is the most robust and attractive system for strengthening security of supply, as it reduces the need for subsidies, thereby relieving the public budget, requires no surcharges, and can be implemented immediately without the need for state aid approval.

Capacity markets entail distorted incentives, externalities, and political interference. Furthermore, in light of the current investment restraint (attentism), it is likely that uncertainty will persist until all detailed rules are finalised. It is therefore more sensible to improve the incentive system of the electricity market at its root. By implementing the hedging obligation immediately, incentives can take effect earlier and trigger new investments. Moreover, total system costs are lower in a competitive electricity market with a hedging obligation, as it stimulates appropriate technological solutions and innovations.

# Bibliography

**Aagaard et al. (2022):** Too much is never enough: Constructing Electricity Capacity Market Demand, Todd Aagaard, Andrew N. Kleit, Energy Law Journal; Washington Bd. 43, Ausg. 1, (2022): 79-124.

**ACER (2020):** Technical specifications for cross-border participation in capacity mechanisms, 22. December 2020.

**ACER (2022):** ACER's Final Assessment of the EU Wholesale Electricity Market Design April 2022.

**Acer (2023a):** Demand response and other distributed energy resources: what barriers are holding them back – 2023 Market Monitoring Report, 19. December 2023.

**ACER (2023b):** Report on Electricity Transmission and Distribution Tariff Methodologies in Europe, January 2023.

**AGEB (2024):** Stromerzeugung nach Energieträgern (Strommix) von 1990 bis 2023 (in TWh) Deutschland insgesamt (Datenstand April 2024), Berlin.

**Battery Charts (2024):** battery-charts.rwth-aachen.de, letzter Zugriff: 23. Juni 2024.

**BDEW (2014):** Versorgungssicherheit wettbewerblich und effizient gewährleisten – Branchenvorschlag für einen dezentralen Leistungsmarkt, BDEW Bundesverband der Energie- und Wasserwirtschaft e. V., Juni 2014, Berlin.

**State Aid Guidelines (2022):** Guidelines on State aid for climate, environmental protection and energy (2022/C 80/01).

**Bloomberg (2023):** Gaspreis steigt 40% - so stark wie kurz nach Ukraine-Invasion, Online: 9. August 2023. Zugriff: 30. April 2024.

**BMWK (2023a):** AG 3 Steuerbare Kapazitäten, 1. Sitzung, Plattform Klimaneutrales Stromsystem (PKNS), Bundesministerium für Wirtschaft und Klimaschutz, 3. Mai 2023, Berlin.

**BMWK (2023b):** Gesetzlicher Smart-Meter-Rolloutfahrplant, Infografik, Bundesministerium für Wirtschaft und Klimaschutz, 11. Januar 2023.

**BMWK (2024a):** Neue Langfristszenarien für die Energiewende, Datenbasis: Langfristszenarien.de.

**BMWK (2024):** Einigung zur Kraftwerksstrategie, Pressemitteilung, Bundesministerium für Wirtschaft und Klimaschutz, 5. Februar 2024.

**BNetzA (2023a):** Bedarfsermittlung 2023 – 2037/2045, Bestätigung Netzentwicklungsplan Strom, Bundesnetzagentur, Bonn.

**BNetzA (2023b):** Versorgungssicherheit Strom, Stand und Entwicklung der Versorgungssicherheit im Bereich der Versorgung mit Elektrizität, Bundesnetzagentur, Januar 2023, Bonn.

**BNetzA (2024a):** Kraftwerksliste, Bundesnetzagentur, Bonn.

**BNetzA (2024b):** Einleitung eines Verfahrens zur Änderung der Festlegung zur Anpassung und Ergänzung von Voraussetzungen für die Vereinbarung individueller Netzentgelte für den Netzzugang, Az: BK4-22-089A02, Beschlusskammer 4, Bundesnetzagentur, Bonn.

**Bobbio (2022):** Price Responsive Demand in Britain's Electricity Market, Emanuele Bobbio, Simon Brandkamp, Stephanie Chan, Peter Cramton, David Malec, Lucy Yu, Econtribute, Discussion Paper No. 185.

**Bundeskartellamt (2023):** Wettbewerbsverhältnisse im Bereich der Erzeugung elektrischer Energie 2022, Marktmachtbericht, August 2023, Bonn.

**Bundesregierung (2021):** Koalitionsvertrag zwischen SPD, Bündnis 90/Die Grünen und FDP, 24. November 2021.

**Connect (2014):** Leitstudie Strommarkt. Arbeitspaket Optimierung des Strommarktdesigns, Connect Energy Economics GmbH, Study commissioned by Bundesministeriums für Wirtschaft und Energie, 2014.

**Connect (2021):** Kapazitätskredit erneuerbarer Energien – welchen Beitrag zur Versorgungssicherheit können Wind- und Solarenergie leisten? Connect Energy Economics GmbH, Study commissioned by Umweltbundesamtes, 2021

**Consentec (2023):** Ansätze zur Stärkung des wettbewerblichen Strommarkts („Strommarkt-plus"), AG 3 Steuerbare Kapazitäten – 4. Sitzung, Plattform Klimaneutrales Stromsystem (PKNS), 16. November 2023.

**Cramton et al. (2013):** Capacity Market Fundamentals, Peter Cramton, Axel Ockenfels, Steven Stoft, Economics of Energy & Environmental Policy, Vol. 2, No. 2.

**Cramton et al. (2023):** A Forward Energy Market to Improve Resiliency, Peter Cramton, Simon Brandkamp, Jason Dark, Darrell Hoy, Albert S. Kyle, David Malec, Axel Ockenfels and Chris Wilkens, 8. Februar 2024.

**EDF (2024a):** Grille de prix de l'offre de fourniture d'électricité – Tarif Bleu, Applicable au 1er février 2024, EDF SA.

**EDF (2024b):** Option Tempo - Faites des économies sur votre facture d'électricité en décalant vos consommations, https://particulier.edf.fr/fr/accueil/gestion-contrat/options/tempo/details.html, last access: 25. Juni 2024.

**Elia (2019):** Overview of Belgian CRM Design: introduction note, September 2019, Elia.

**Energie Lexikon (2024):** Energie-Lexikon.info.

ENTSOE (2024): Entsoe Transparency Plattform, 2024.

**EnWG (2024):** Energiewirtschaftsgesetz, Bundesministerium der Justiz, https://www.gesetze-im-internet.de/enwg_2005/.

**EU Electricity Market Directive (2019):** Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU.

**EU Electricity Market Directive (2024):** Directive (EU) 2024/1711 of the European Parliament and of the Council of 13 June 2024 amending Directives (EU) 2018/2001 and (EU) 2019/944 as regards improving the Union's electricity market design.

**EU Electricity Market Regulation (2019):** Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity.

**EU Electricity Market Regulation (2024):** Regulation (EU) 2024/1747 of the European Parliament and of the Council of 13 June 2024 amending Regulations (EU) 2019/942 and (EU) 2019/943 as regards improving the Union's electricity market design.

**FfE (2024):** Haushaltsnahe Flexibilitäten nutzen – Wie Elektrofahrzeuge, Wärmepumpen und Co. die Stromkosten für alle senken können, Forschungsstelle für Energiewirtschaft e. V. (FfE), Agora Energiewende, Januar 2024.

**Frontier Economics (2023):** Wert von Großbatteriespeichern im deutschen Stromsystem, Study commissioned by BayWa r.e. AG, ECO STOR GmbH, enspired GmbH, Fluence Energy GmbH und Kyon Energy Solutions GmbH, Dezember 2023.

**Gramlich et al. (2019):** Too much of the Wrong Thing: The Need for Capacity Market Replacement or Reform, Rob Gramlich, Michael Goggin, Study for Sustainable FERC Project, Grid Strategies LLC, November 2019.

**Hirth et al. (2024):** How aggregate electricity demand responds to hourly wholesale price fluctuations, Lion Hirth, Tarun M. Khanna, Oliver Ruhnau, Energy Economics 135 (2024).

**IMF (2024):** Climate Change – Fossil Fuel Subsidies, International Monetary Fund, https://www.imf.org/en/Topics/climate-change/energy-subsidies, 2024

**Kahnemann und Tversky (1979):** Prospect Theory: An Analysis of Decision under Risk, Daniel Kahneman and Amos Tversky, Econometrica, Vol. 47, No. 2 (Mar., 1979), pp. 263-292.

**KapResV (2019):** Verordnung zur Regelung des Verfahrens der Beschaffung, des Einsatzes und der Abrechnung einer Kapazitätsreserve, 2019.

**Knight, Frank (1921):** Risk, Uncertainty and Profit, Boston and New York: Houghton, Mifflin Company. 1921.

**Krueger (1974):** The Political Economy of the Rent-Seeking Society, Anne O. Krueger American Economic Review, 1974, vol. 64, issue 3, 291-303.

**Meyer-Braune und Lopion (2023):** Rolle lokaler Signale bei Finanzierung steuerbarer Kapazitäten, Georg Meyer-Braune (50 Hertz) and Peter Lopion (Amprion), 4. Sitzung der AG 3 Steuerbare Kapazitäten, Plattform Klimaneutrales Stromsystem (PKNS).

**Modo Energy (2024):** Capacity Market 2024: T-4 auction results in 5 charts, Modo Energy.

**Monopolkommission (2023):** Energie 2023: Mit Wettbewerb aus der Energiekrise, 9. Sektorgutachten, Monopolkommission, 9. Oktober 2023, Bonn.

**National Grid (2014-2024):** Capacity Market Auction Guidelines.

**Neon (2023a):** Windstrom nutzen statt abregeln – Ein Vorschlag zur zeitlichen und räumlichen Differenzierung der Netzentgelte, Study commissioned by Agora Energiewende, Neon Neue Energieökonomik GmbH, August 2023.

**Neon (2023b):** Stromtarife für Preissicherheit und Flexibilität – Ausgestaltung eines dynamischen Tarifs mit Preissicherheit, Study commissioned by LichtBlick SE, Neon Neue Energieökonomik GmbH, 21. September 2023).

**Neon et al. (2019):** Kosten- oder Marktbasiert? Zukünftige Redispatchbeschaffung in Deutschland – Schlussfolgerungen aus dem Vorhaben „Untersuchung zur Beschaffung von Redispatch", Abschlussbericht, Neon, Consentec, Connect, Navigant, SUER, 7. Oktober 2019.

**Neon (2024):** Mehrwert dezentraler Flexibilität – Oder: Was kostet die verschleppte Flexibilisierung von Wärmepumpen, Elektroautos und Heimspeichern?, Study commissioned by Verbands der Elektro- und Digitalindustrie (ZVEI e.V.), 14. März 2024.

CONNECT

**Nicolosi (2010):** Wind power integration and power system flexibility – An empirical analysis of extreme events in Germany under the new negative price regime, Marco Nicolosi, Energy Policy Volume 38, Issue 11, November 2010.

**Prognos (2022):** Strompreisprognose 2022, Gutachten für die vbw – Vereinigung der Bayerischen Wirtschaft e. V., 21. September 2022.

**Rinck (2015):** Die Rolle der Börse im EOM 2.0, Maximilian Rinck, Strommarkttreffen, 27. November 2015.

**Schleich (2022):** Neubau-Vorschuss: Anreize für den Neubau gesicherter Leistung im Strommarkt, Strommarkttreffen: „Strommarktdesign: Kriseninterventionen, Großhandel, Kapazitätsmärkte/-Reserven“, Sebastian Schleich, Transnet BW, 2. September 2022.

**StromNEV (2023):** Verordnung über die Entgelte für den Zugang zu Elektrizitätsversorgungsnetzen, Bundesministerium der Justiz.

**Taleb (2018):** Skin in the Game – Hidden Asymmetries in Daily Life, Nassim Nicholas Taleb, Random House.

**UBA (2023):** Nationale Trendtabellen für die deutsche Berichterstattung atmosphärischer Emissionen, Umweltbundesamt, Dessau.

**UCTE (2004):** Operation Handbook, Union for the Co-ordination of Transmission of Electricity.

**Wawer (2022):** Elektrizitätswirtschaft: Eine praxisorientierte Einführung in Strommärkte und Stromhandel. Wiesbaden: SpringerGabler, 2022.

**Wolak (2021):** Wholesale Electricity Market Design, Handbook on Electricity Markets, Frank Wolak, Hrsg. Jean-Michel Glachant, Paul L. Joskow and Michael G. Pollitt, Edward Elgar Publishing.