UNIVERSITY OF PIRAEUS
Department of International & European Studies
MSc in Energy: Strategy, Law and Economics

Capacity mechanisms within the EU internal electricity market as a response to security of supply and energy transition

Written by:

Maria Arvaniti, MEN 24005

Thesis Supervisor:

Professor Michael Polemis

Piraeus, March 2026

The intellectual work fulfilled and submitted based on the delivered master thesis is exclusive property of mine personally. Appropriate credit has been given in this diploma thesis regarding any information and material included in it that have been derived from other sources. I am also fully aware that any misrepresentation in connection with this declaration may at any time result in immediate revocation of the degree title.

Abstract

The thesis aims to answer whether and under which conditions capacity mechanisms (CMs) can effectively address security of supply in EU internal electricity market as well as the energy transition. It also embeds current CM practice within a shift from the energy-only market (EOM) framework towards a capacity-dominated market design.

Methodologically it contributes by providing: (i) structured literature review on legal, economic and policy knowledge available with respect to EOM, missing-money problem and EU adequacy governance, (ii) empirical cross-sectional analysis in 27 European states mainly exploiting ACER monitoring data for measures on wholesale price volatility, renewable energy sources (RES) penetration, capacity-market design parameters and adequacy metrics, (iii) a simplified Cournot model of a capacity market that examines how adequacy assumptions and market concentration affect equilibrium capacity prices and quantities.

The empirical findings show that the wholesale daily price spread in countries with CMs is lower than across EOM even when controlling for RES contribution and some other structural indicators. CM arrangements are currently fossil fuel dependent with limited cross-border participation while the CM costs per capita vary significantly even for countries with a similar level of security of supply. The Cournot analysis highlights the importance of capacity prices as adequacy signals which are likely to exceed the cost of new entry in a concentrated market when reliability is highly regarded.

The thesis argues that CMs have become a part of the EU's security of supply policy even if CMs role to energy trilemma is still ambiguous. Enhanced harmonisation of adequacy governance, regional integration and competitiveness mechanisms along with improvements in the alignment of CM performance incentives with flexibility and decarbonisation priorities will support a capacity-dominated market design in the future.

Acknowledgements

I would like to express my sincere gratitude to my thesis supervisor, Professor Michael Polemis, for granting me the opportunity to explore such a compelling and meaningful subject. His guidance, support, and encouragement have been truly invaluable throughout this process.

I am also deeply grateful to my family and close friends for their support, understanding, and patience during the months dedicated to the completion of this thesis.

Table of contents

List of tables

List of figures

1. Introduction

In the debate on EU electricity market design capacity mechanisms re-emerged as a cornerstone. Wholesale energy markets have been incrementally liberalised since the 1990s and energy-only market design introduced to convey efficient investment signals in terms of marginal-cost prices and scarcity rents. However, as there are growing concerns over missing-money problem alongside increased decarbonisation ambitions and geopolitical shocks, energy-only market role in security of supply, affordability and decarbonisation, the three elements of the energy trilemma, has been diminished.

The weaponisation of Russian gas supplies and the structural tightness of generation capacity driving gas and electricity price spiking during the period 2021-2023, has exposed the fragility and dependency of EU energy system and the broader macroeconomic relevance of affordable and reliable electricity generation. ACER (2025) has also linked security of supply to the EU's competitiveness and recent EU policy documents (European Parliament and Council, 2024) explicitly present adequacy policy as an important tool for addressing energy trilemma.

In this framework, an increasing number of Member States are using capacity mechanisms to pay for availability of capacity in addition to energy-market revenues. These are forms of investment risk transferred from market participants to consumers, able to adjust the speed and direction of decarbonisation and are justified formally as planned, proportionate responses to existing resource adequacy concerns under the EU Electricity Regulation (European Commission, 2025). A review of the evidence shows that €90 billion has been distributed in European capacity markets since 2014 with over two-thirds of this support awarded to thermal technologies and gas-fired assets accounting for around half of all payments contracted (Aurora Energy Research, 2025). However, do the existing capacity-mechanism designs fully reflect long-term climate-neutrality goals, or do they risk locking in new fossil capacity to the 2040s and beyond?

Concurrently, the regulatory State aid framework of capacity mechanisms is changing fast. In the 2019 Electricity Regulation capacity mechanisms were at first cast as ‘last resort’ measures with strict adequacy tests to be founded on the European Resource Adequacy Assessment (ERAA) and exacting technology-neutral contests and emission performance standards (European Parliament and Council, 2019). More recently, an EU electricity market-design reform has been introduced by the European Parliament and Council in 2024, and the European Commission (2025) has also published a report to facilitate the approval of capacity mechanisms. To this extent, the Commission has adopted in 2025 the Clean Industrial State Aid Framework (CISAF) which introduced dedicated provisions for capacity mechanisms with fast-track approval procedures based on two ‘target models’ including a market-wide central-buyer scheme and a strategic reserve. Pursuant to this framework, if Member States design their schemes according to these target models and base them on ERAA then the Commission can perform a streamlined compatibility assessment which reduces complexity of procedures and provides ex-ante clarity on compliant design elements. CISAF is also intended to help drive more convergence in capacity-mechanism design across the EU internal electricity market which would ease cross-border competition and reduce administrative barriers to investors.

The most recent set of EU reports highlight that decisions on resource adequacy and system flexibility are fundamentally intertwined. The 2025 Monitoring report of ACER (ACER, 2025) recognises a proliferation of overlapping national measures, capacity mechanisms, flexibility schemes and other security of supply tools and emphasises that treating adequacy and flexibility in isolation may lead to inefficient procurement and double remuneration. It suggests Member States to explicitly identify the interdependence between flexibility and adequacy needs, co-optimise their procurement and award them in a way consistent with the Electricity Regulation and the newly developed CISAF (ACER, 2025). Meanwhile, ACER (2025) also highlights in the assessment of cross-border participation the advantages for Member States if the potential of neighbouring resources was fully exploited, including capacity contracted in mechanisms in other countries, with potentially less national capacity procured, whilst being able to reach the same reliability standards thus lowering the total cost of security of supply. But today's practice with its minimal regional adequacy alignment may not be living up to that potential.

These developments bring into focus a larger strategic question that lies at the heart of this thesis. As renewables make up a greater share of generation and short-run marginal costs of generation decline, the prominence of energy-only markets as the primary price formation mechanism may gradually recede. In a deeply decarbonised system over the next 15-20 years, wholesale energy prices are expected to be low for most hours with relatively rare scarcity events. This limits the scope of fixed costs recovery and consequently weakens investment signals from the energy-only market. Therefore, the core economic issue of financing and coordinating sufficient and flexible capacity is expected to be addressed through capacity mechanisms. Within a capacity-dominated market design, spot prices would increasingly reflect the production and network costs of real-time balancing energy while long-term investment signals would be provided mainly through capacity mechanisms. In such a context most resources, whether generation, storage, transmission, distribution and demand response, would recover the bulk of their revenues from their capacity value rather than from energy value.

By contrast, the literature dealing with capacity mechanisms focuses mainly on their implementation as incremental add-ons to energy-only market and seems to be less insightful in terms of what a capacity-dominated market design might look like, how it should interact with flexibility support and cross-border integration and to what extent it can remain compatible with the energy trilemma.

Against this background, the thesis aims to review whether and to what extent capacity mechanisms in the EU internal electricity market can constitute an appropriate answer to security of supply and the energy transition. In particular, it deals with three interrelated questions:

1. How the emergence and evolution of capacity mechanisms in EU electricity markets relates to the historical evolution of energy-only markets, the missing-money problem and the legacy of former monopoly systems and resources endowments?

2. What is the extent of any such observable differences in wholesale price volatility, adequacy-related parameters and consumer cost burdens associated with existing EU capacity mechanisms, and how do these outcomes compare and relate to the broader framework of security of supply measures?

3. What design principles and governance arrangements will be needed for future capacity-dominated market designs to support security of supply, affordability and decarbonisation?

In order to answer these questions, the thesis brings together three methodological components. It first delivers a structured literature review of liberalisation and energy-only market design, the economics and taxonomy of capacity mechanisms and the emerging EU regulatory and State aid framework for adequacy policy. The literature review traces the transition from energy-only markets to the development of capacity mechanisms and the EU adequacy and State aid frameworks by identifying a research gap since capacity mechanisms are usually characterised as add-ons to energy-only markets without considering empirical evidence and forward-looking market design aspects. Second, it constructs an empirical analysis using a region-wide cross-sectional dataset of 27 European countries, which has been compiled from ACER security of supply reports, ACER electricity country sheets and other official sources to depict price volatility, adequacy parameters, capacity mechanism costs and technology composition and to econometrically assess the association between capacity mechanism status, renewable penetration and wholesale price dispersion across Member States with and without capacity mechanisms. The empirical section addresses the second research question by estimating econometric relationships among capacity mechanisms, wholesale price dispersion and renewable penetration. Third, it uses a reduced form calibration to the adequacy framework in order to build a simplified Cournot model to examine the expected capacity price and quantity responses in a future capacity-dominated market. The Cournot model serves as a simple representation of a future capacity-dominated market design illustrating how capacity prices may respond to different adequacy standards and market concentration. To this extent, these components contribute to the main discussion of the thesis which concerns the conditions under which capacity mechanisms can support energy trilemma in the EU internal electricity market

This thesis seeks to contribute to the ongoing debate of how electricity markets can be re-engineered in a manner that is consistent with the EU long-term climate and competitiveness objectives by performing a critical review of the theoretical and policy literature with empirical evidence and a simple analytical model. It especially aims to explain how capacity mechanisms can be integrated into a stable mainly capacity-dominated market framework providing security of supply, low electricity prices and decarbonisation.

2. Literature review

2.1 Liberalisation & Energy-Only Markets

The liberalisation of the electricity sector in the EU took place gradually through numerous individual energy packages that opened national monopoly markets to competition and established internal energy market principles. The first package, under the name of First Energy Package (from 1996 and 1998), initiated the liberalisation process of national energy markets while the second one, i.e. Second Energy Package (2003) offers to industrial and household users the possibility of choosing their suppliers from a list that has been broadened with more competitors (European Parliament, 2025). This was further developed with the Third Energy Package (2009) which included unbundling of transmission networks from supply and generation, stronger national regulators, ACER and effectively interconnected cross-border market through European networks of transmission system operators (European Parliament, 2025). The Fourth Energy Package renewed the market architecture with new provisions on renewables, consumer engagement and restrictions on subsidies including capacity mechanisms, while the so-called 'Clean Energy for All Europeans' package approved in 2019 included requirement of preparedness to risk in electricity (European Parliament, 2025). It should be noted that the Electricity Regulation (EU) 2019/943 and the Electricity Directive (EU) 2019/944 institutionalised marginal-cost-based price formation as method of establishing wholesale prices as a default in the internal market for electricity and stipulated that remuneration should be mainly for energy sold than capacity installed (European Parliament and Council, 2019).

The legal framework sets the energy-only market model whereby generators are remunerated through receiving short-term electricity market revenues. The wholesale price is determined in auctions where the clearing price is established frequently (e.g. hourly) by the marginal unit. In this perspective, it is considered that long-run investment costs are repaid by inframarginal rents or irregular extreme price events (Harvey and Hogan, 2023). Frontier Economics (2023) further explains that although a specifically dedicated capacity payment does not exist, the market design includes an implicit one because suppliers and balance-responsible parties need to make sure that they are able to supply the contracted energy in real-time and incur imbalance costs when they fail to do so. The justification is found in the theory of peak-load pricing. When demand is low, prices tend to be around the short-run marginal cost of the marginal generating unit and when demand approaches available capacity prices are high due to scarcity events. Over time, the combination of low prices across most hours and high prices in case of scarcity events is anticipated to allow plants to recover their fixed costs (Frontier Economics 2023). The EU in fact incorporated this logic in its governance design, based on the premise that as long as under effective competition and undistorted scarcity pricing conditions energy and balancing markets function properly, there is no reason to incorporate permanent capacity mechanisms (European Parliament and Council, 2019).

Even then, though, structural characteristics of the European power market limited the design effectiveness of energy-only market. The liberalisation was performed in energy systems which were based on incumbent amortised assets owned by former monopolies. Historically, incumbent resources had very low operating costs been able to run profitably at very low wholesale prices while effectively suppressing scarcity events and limiting revenue opportunities for new entrants (Grubb, 2023). Moreover, the historical resource endowments were not evenly spread across Member States so that members that counted on substantial hydro, nuclear and lignite had a completely different price setting than countries relying on new thermal assets (ACER, 2024). Thus, it created asymmetric returns to investment because the costs of capital were lower for incumbents that could accept lower bids than new investors with higher cost of debt and more regulatory uncertainty.

The regulatory interventions further constrained scarcity pricing. The political sensitivity of the levels for electricity prices created constraints manifested in administrative price caps, capacity withholding rules and substantial control of retail prices. Market power mitigation policies were initially designed to dampen the market power of incumbents, however they had the coincidental effect of suppressing necessary long term price signals (Frontier Economics, 2023). New tools, which have been created during the energy crisis (i.e. revenue cap, bid cap in balancing market and emergency price suppression), have further weakened the wholesale markets as a signal for stress events (ENTSO-E, 2025).

Joskow (2008) identifies several reasons why energy-only markets often do not provide adequate incentives to invest in sufficient capacity to meet administrative reliability requirements including price caps that suppress prices below market clearing levels during scarcity conditions, imperfections on the demand side, out-of-market actions by system operators, and inconsistencies between administrative reliability criteria and consumer preferences for reliability. In that context, he argues that well-designed capacity mechanisms can support more efficient investment in generation adequacy in imperfect electricity markets (Joskow, 2008).

There are also structural issues that have been compounded by decarbonisation. In particular, as the penetration of renewables increases the marginal cost tends towards zero which depresses not only wholesale prices and inframarginal rents but also the viability of scarcity pricing as a foundation for investments in capacity and flexibility resources (i.e. storage, demand response). Frontier economics (2023) highlights that given renewables gradual penetration scarcity events will become rare resulting in a reduced investment capacity. Lebeau et al. (2024) also underline the new adequacy issues that occur in deep decarbonised systems that an energy-only market was not initially designed to address.

2.2 Capacity mechanisms characteristics

Conceptually, capacity mechanisms are policy tools that ensure the availability of resources to supply capacity. While energy-only markets are paid for each megawatt-hour they deliver, capacity mechanisms provide a remuneration associated with the commitment of being available to supply if a system crisis occurs (Frontier Economics, 2023).

Therefore, even though the design of the capacity mechanisms varies significantly between Member States, European capacity mechanisms exhibit several common features. All of the capacity mechanism types involve the forward procurement of capacity multiple years ahead of delivery (Simoglou and Biskas, 2023). The forward dimension aims to provide enough certainty for future investments and the needed lead time for new resources to be developed and commissioned. A capacity obligation is defined, meaning that resources offer to be made available during defined hours or system conditions and face penalties if they do not deliver when needed (Simoglou and Biskas, 2023). Finally, each scheme is also, at least in principle, technology-neutral, therefore allowing all resource types to compete on an equal basis with fossil-fuel technology subject to emissions-related eligibility criteria (European Commission, 2025).

Regarding market design, capacity mechanisms create a new product, capacity, to be traded together with energy. Frontier Economics (2023) stresses that in the EU context capacity is defined in terms of reliable availability during stress periods and not continuous output while preserving the basic dispatch logic of an energy-only market by procuring sufficient capacity at minimum cost. From a regulatory perspective, the European Commission regards capacity mechanisms as market design interventions that can be justified under State aid rules if Member States can prove there is indeed an adequacy concern and that less distortive measures are not effective (European Commission, 2025). From the perspective of economic analysis, capacity mechanisms are institutional responses to market failures in long-term investment of energy-only market pricing (Frontier Economics, 2023).

The missing-money problem is considered the main economic rationale for the introduction of capacity mechanisms. In the energy-only market, scarcity values have to reach levels that reflect consumers' willingness to pay whilst providing generators with sufficient revenue over the long run to recover their fixed costs. For various reasons described in section 2.1, though, genuine scarcity pricing as such does not happen in European electricity markets. Capacity mechanisms address the missing-money problem by decoupling part of the capacity payment from the price volatility. Instead of being dependent on infrequent periods when resource scarcity prices prevail in the market, resources get a dependable capacity payment in return for promising to be available during certain pre-established stress points. According to theory (Frontier Economics, 2023), well-designed capacity mechanisms may be able to recover investment incentives whilst maintaining efficient short-run dispatch determined by marginal-cost pricing in the electricity market.

Cramton and Stoft (2006) show that various approaches to resource adequacy, from energy-only designs with call options to market-wide capacity markets, tend to have a common set of principles that include an explicit reliability target, forward procurement of capacity obligations and financial penalties while short-run dispatch is governed by marginal-cost pricing. It should be noted however, as Newbery (2015) argues, that standard capacity auction designs often tend to over-procure capacity because volumes are determined conservatively by governments and system operators. As a result, wholesale prices are depressed and can thereby aggravate the missing-money problem that capacity mechanisms are intended to address. Moreover, incomplete hedging markets and uncertain revenues for flexibility and interconnection can limit the effectiveness of both energy-only markets and capacity mechanisms in delivering reliability (Newbery, 2015).

Capacity mechanisms were not an essential tool when liberalisation of the EU electricity market initiated. Although adequacy issues were addressed primarily through national planning, TSO reliability requirements and in certain instances conventional long-term contracts between incumbents and the state, it was a matter of time before formal capacity mechanisms started to be investigated by Member States (Simoglou and Biskas, 2023). The first comprehensive rollout in Europe was the Great Britain capacity market holding auctions in 2014 for the delivery year 2018 (Aurora Energy Research, 2025). France initiated in 2017 a decentralised capacity obligation scheme according to which suppliers are obliged to demonstrate that they have sufficient capacity certificates in order to cover peak demand (Simoglou and Biskas, 2023). Poland's capacity market was approved as State aid in 2016 with first delivery obligations from 2021 due to concerns over the ageing coal fleet and future adequacy (Simoglou and Biskas, 2023). A subsequent wave of adoptions has included Ireland's capacity mechanism in 2018, Italy's market-wide auctions in 2019 and Belgium's capacity mechanism in 2022 (Aurora Energy Research, 2025). At the same time, a few Member States selected strategic reserves instead of market-wide capacity market. In a strategic reserve, plants are maintained out of the energy market as a reserve and dispatched only during scarcity eventa (see section 2.4 for an overview of different types of capacity mechanisms). According to the monitoring report of ACER (2024), Germany, Finland, and Sweden have chosen the strategic reserve as their primary policy to ensure adequacy.

At the start, the European regulatory approach considered capacity mechanisms to be a temporary measure. Under State aid control Member States must first identify a clear adequacy problem, then show that the identified problem cannot be solved by less distortive measures and finally establish that mechanisms are based on need, proportionality and open to cross-border participation (European Commission, 2025). Each mechanism was evaluated on its own merits, focusing in particular on the avoidance of distortions to the internal market being continued for lengthy periods and that energy-only market was maintained as the principal form of providing investment signals. But over time, certain elements have led capacity mechanisms to become more structural within the EU internal market. ACER's monitoring report on security of electricity supply in the EU (2024) concludes that capacity mechanisms have emerged as a significant part of the adequacy toolbox in several Member States and will likely continue to be needed as the system decarbonises.

The 2024 reform of the EU electricity market design is another illustration of capacity mechanisms evolution. It proposes to keep energy-only markets as the cornerstone of price formation but acknowledge a more permanent function for well-designed capacity mechanisms subject to simplified approvals procedures and with increased coordination on an EU level (European Commission, 2024). Furthermore, CISAF (2025) brings in target models for capacity mechanisms and a fast-track approval procedure whenever these models are respected, marking a tendency toward higher standardisation and long-term integration of capacity mechanisms into the EU internal market framework.

Notwithstanding these studies and policy documents, many of them continue to analyse capacity mechanisms as complements to energy-only markets and few consider how a primarily capacity-dominated market design could work long term, especially in a world under deep decarbonisation and widespread electrification. This represents a significant gap that subsequent chapters attempt to fill by way of framing capacity-mechanism design in relation to future adequacy governance and capacity-dominated market architecture.

2.3 The EU framework

The initial European capacity mechanisms were conceived and adopted as measures for the market at the national level in the context of reformulation of adequacy considerations, following notifications to the European Commission under State aid rules. With increasing number of Member States contemplating similar measures, growing concerns emerged that non-coordinated national solutions would lead to a fragmentation of the internal market, distort cross-border trading as well as jeopardise the emerging pan-European electricity market (ACER, 2025).

These concerns were one of the reasons behind the 2019 'Clean Energy for all Europeans' package which sought to create a more centralised framework on resource adequacy and capacity mechanisms at the EU level. Regulation (EU) 2019/943 on the internal market for electricity and Regulation (EU) 2019/941 on risk preparedness are, together with Regulation (EU) 2019/942 in relation to ACER and Directive (EU) 2019/944 on common rules for the internal market in electricity, the legal pillars of that framework (European Parliament, 2025). Indeed, the 2024 revision of the design of the electricity market explicitly highlights that the package sought to reinforce the internal energy market while guaranteeing security of supply and supporting decarbonisation (European Parliament and Council, 2024).

Under this architecture Chapter IV of Regulation (EU) 2019/943 introduced a special regime for capacity mechanisms. It specifies the conditions to be met in order for such mechanisms to be implemented, establishes the criteria for justifying them and lays down rules to guarantee that they do not distort excessively the internal market or replace essential market reforms (European Parliament and Council, 2019).

The special electricity market provisions are supplemented by EU State aid law, in this case Art 107 TFEU and the 2022 Guidelines on State aid for climate, environmental protection and energy (CEEAG) (European Commission, 2022). The relevance of the system adequacy criterion becomes apparent in reference to the European Commission's streamlining report, according to which the Electricity Regulation and CEEAG together form the legal framework for assessing security of supply measures including capacity mechanisms (European Commission, 2025). This hybrid structure of sectoral regulation and competition policy is aligned with the double nature of capacity mechanisms as market design instruments and selective support schemes with potential impacts on competition and commerce.

The 2024 market design reform is a major rewrite of the original articulation that capacity mechanisms were strictly temporary last-resort measures. The principle that the energy-only market shall be the main tools to ensure adequacy is, however, preserved in this revised framework according to which capacity mechanisms should no longer be considered as measures of last resort but their need and design should be periodically reviewed in view of the changing regulatory environment or development of the markets (European Parliament and Council, 2024).

2.4 Typology of capacity mechanisms

Capacity mechanisms are classified based on their scope of application (targeted versus market-wide) and the form of remuneration they provide to suppliers (quantity vs price-based). According to ENTSO-E (2025) this entails four different designs which are described below:

Targeted mechanisms are limited to specific resources and usually phased in as solutions to local or short-term adequacy issues.

- Among the quantity-based mechanisms, there are:
  - Targeted tenders in which a centrally coordinated process takes place to ensure the construction of specified volume of a new capacity (often of a specific technology or geographical location).
  - Strategic reserves which aim to secure a certain quantity of capacity outside the wholesale market targeting existing generation and demand side response.
- Targeted capacity payment is a price-based mechanism in which a payment of an administratively established capacity price is performed to a subset of capacity.

On the other hand, market-wide mechanisms apply to all eligible capacity resources in the system and are designed to address structural adequacy needs.

- Among the quantity-based mechanisms, there are:
    - Availability product in which a competitive bidding process takes place for an availability obligation which is based on a capacity requirement determined centrally that has to achieve a defined security standard.
    - Decentralised obligations, where electricity retailers are mandated to contract with capacity providers in order to cover their overall demand.
    - Centralised reliability options set a financial obligation to capacity providers for delivery of energy.
    - Decentralised reliability options allow every market participant to trade options with capacity providers.
- Market-wide capacity payment is a price-based mechanism that establishes a specific price for capacity which is defined using certain algebra or on an administered basis.

Figure 1 illustrates a map of the use of capacity mechanisms across Europe in 2025.

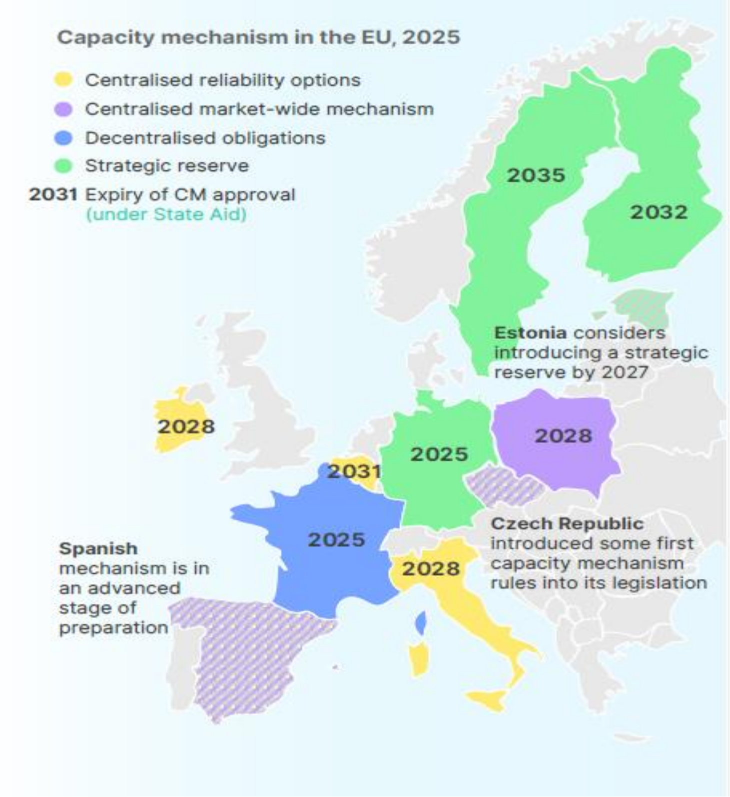


Figure 1: Capacity mechanisms across Europe in 2025

Source: ACER Security of EU electricity supply Monitoring Report, 2025

According to ACER (2025) the following countries have capacity mechanisms:

• Belgium, Ireland, Italy and Poland use a market-wide capacity mechanism with a central buyer model;

• France applies a market-wide capacity mechanism using decentralised obligations;

- Germany, Finland and Sweden have strategic reserve schemes.

2.5 Capacity mechanism preconditions

The EU scheme does not facilitate the random introduction of capacity mechanisms by its Member States. Rather it creates a chain of pre-conditions that need to be met before a mechanism can be deemed justified and internal market compatible.

First, the Member States have to establish a reliability standard that reflects what constitutes an acceptable level of risk in adequacy. Pursuant to Article 25 of Regulation (EU) 2019/943, such standard shall be based on a common methodology developed by ACER and shall include at least the value of lost load (VoLL) and the cost of new entry (CONE) over a relevant period. The ACER methodology (ACER, 2020) states that the reliability standard should be quantified in a manner which weighs the cost of higher installed capacity against the societal cost of unserved energy, usually based on loss of load expectation (LOLE) and expected energy not served (EENS). The objective is to have socio-economically efficient reliability standards in place among the Member States, although de facto implementation has been varying up till now.

Secondly, formal examinations should be used to demonstrate adequacy issues. In accordance with Article 24 of Regulation (EU) 2019/943 Member States are obliged to monitor adequacy on the basis of European Resource Adequacy Assessment (ERAA), which is prepared by ENTSO-E via a probabilistic method and approved by ACER. ERAA employs Monte Carlo simulations of energy categories, renewable output, forced outages and interconnector availability to develop probabilistic security of supply indicators (such as LOLE and EENS) (ACER, 2020). The ERAA has a 10-year outlook, incorporates standard reference cases and analyses economic resource adequacy (ACER, 2020). Consistent with ACER's VoLL, CONE and reliability standard methodology (hereafter referred to as 'Methodology for the CONE, VoLL and RS'), the LOLE and EENS outputs are combined with assumptions about the VoLL and the CONE to determine whether modelled resources are economically adequate to achieve a given standard of reliability or whether there is an 'adequacy gap' (ACER, 2020). In ERAA, the Economic Viability Assessment (EVA) module reviews annuitised fixed and variable costs against anticipated market revenues for each technology and bidding zone to categorise economic viability for resources under a given market design assumption (ACER, 2020). National resource adequacy plans may serve as supplements to the ERAA but are required to be derived using identical methodology and scenarios, and any deviation from the results of the ERAA must be explained. The 2024 monitoring report from ACER on security of supply confirmed that finally ERAA 2023 was, for the first time after three years, approved, reflecting progress in the implementation of this framework but also stated that both ENTSO-E and Member States do not fully comply with all aspects of adequacy methodology, especially when it comes to the Methodology for the CONE, VoLL and RS (ACER, 2024).

Thirdly, where adequacy problems are found Member States shall develop an implementation plan that solves the fundamental problem through market reforms. Article 20 of Regulation (EU) 2019/943 requires Member States with adequacy concerns to follow this approach and present a plan for reforms (e.g. in scarcity pricing, balancing markets, demand response, interconnectors or removal of regulatory distortions) to the Commission. The 2025 streamlining report of the Commission states that these implementation plans aim to prevent capacity mechanisms from being used as a replacement for enhancement to energy market operations (European Commission, 2025). It also explains that the Commission has adopted guidelines to support Member

States in identifying regulatory distortions and designing their plans, and that it issues an opinion on the plans prior to any State aid assessment of a capacity mechanism (European Commission, 2025). To this extent, only if this sequence has been followed (reliability standard, adequacy assessment, implementation plan) can a capacity mechanism be considered to address an actual adequacy problem that could not instead have been dealt with less distortion.

There have been subsequent developments that provide greater clarity about where ERAA fits into the scheme of EU adequacy governance. In March 2025, as a follow-up to the Commission's report on the streamline of capacity mechanism approval, ACER invited ENTSO-E to make proposals for modifications in ERAA methodology with view to better aligning it with new EU governance framework. On 6 November 2025, ENTSO-E proposed the revised ERAA methodology which ACER targets to adopt by February 2026.The proposal suggests a connection among ERAA outputs, national reliability standards and capacity mechanism design aspects, closer integration of adequacy and flexibility needs and increased cross-border participation.

2.6 Capacity design requirements

The EU framework defines certain capacity design requirements considering that the preconditions presented in section 2.5 are fulfilled. These obligations are largely developed in Chapter IV of Regulation (EU) 2019/943 on the internal market for electricity, within the CEEAG as well as in the European Commission's 2025 report on general assessment and streamlining of capacity mechanisms. They provide, in conjunction, what Member States are allowed to do when establishing capacity mechanisms which could effectively secure adequacy while not leading to any consequences that would be inconsistent with internal market and State aid rules.

A first essential requirement, enshrined already by Article 22 of Regulation (EU) 2019/943, is that capacity mechanisms must be designed to operate on the basis of competitive, market-oriented allocation processes. This implies, in practice, that capacity is fundamentally procured through transparent, non-discriminatory auctions with remuneration reflecting competitive bidding rather than the prices being set administratively. Commission has in recent application under the CEEAG considered auction-based allocation to be a cornerstone of the test of proportionality and it will allow an administratively determined payment only if it is exceptional and well justified (European Commission, 2025). It should be noted that the concept of competitive allocation is to reduce capacity costs to consumers and disclose the marginal cost of adequacy and not to overcompensate individual technologies or incumbents.

The second condition is the principle of technological neutrality and non-discrimination. Under the terms of Regulation (EU) 2019/943, all flexibility resources that could improve adequacy and comply with clearly defined technical requirements should be allowed to participate on an equal basis including generation, storage, demand response and foreign capacity. The CEEAG also mention that State aid shall not discriminate unjustifiably against certain technologies or business models and that all deviations should be objectively justified by environmental reasons or security of supply (European Commission, 2022). Commission has recently focused on opening up capacity mechanisms to demand-side response and storage and eliminating certain discriminatory barriers that were previously in place as part of a larger policy goal regarding flexibility and decarbonisation of power systems (European Commission, 2025). CO_2 emission performance standards restrict the use of high-emitting fossil-fuel plants in market-wide capacity mechanisms, notably with limits on emissions for new capacity and limitations for a transition period on existing capacities are introduced by Regulation (EU) 2019/943. It is worth noting that under Article 22 of Regulation (EU) 2019/943 two circumstances must be fulfilled in relation to capacity mechanisms, namely: (i) as from 4 July 2019 at the latest generation capacity that started commercial production on or after that date and that emits more than 550 g of CO_2 of fossil fuel origin per kWh of electricity shall not be committed or to receive payments or commitments for future payments under a capacity mechanism; (ii) as from 1 July 2025 at the latest, generation capacity that started commercial production before 4 July 2019 and that emits more than 350 kg CO_2 of fossil fuel origin on average per year per installed kWe shall not be committed or receive payments or commitments for future payments under a capacity mechanism.The CEEAG underpin this approach by not only stipulating that aid for security of supply is aligned with decarbonisation objectives but also scrutinising schemes which can potentially lock-in high-emitting technologies.

A third dimension of design concerns obligations of availability and penalty arrangements. Capacity markets are designed to be paid for availability during times of system stress not just for installed megawatts. Regulation (EU) 2019/943 thereby makes it necessary that capacity providers are under clearly defined performance obligations, and the Commission in its compatibility assessments ascertains whether non-availability is penalised in a manner providing credible incentives to deliver when needed. The 2025 report specifies how the Commission assesses for each case in particular the definition of stress events, the level and structure of penalties and interaction between capacity payments and energy market revenues to ensure that capacity remuneration is well aligned with a real contribution to adequacy (European Commission, 2025). Where penalties are weak or not enforced, capacity mechanisms bare the risk of degenerating into basic income support schemes, while where penalties are too severe they may induce non-participation or increase risk premia and the overall system cost (European Commission, 2025).

A fourth set of considerations is related to cross-border involvement, which is crucial part of the design and compatibility checks. Under Article 26 of Regulation (EU) 2019/943, when using a capacity mechanism Member States must permit the participation of foreign capacity on terms that are free from discrimination in principle. To give operational substance to this obligation, ACER has turned these into technical standards which provide clarity on such issues as how Maximum Entry Capacity (MEC) for non-domestic resources is calculated and how responsibilities between TSOs are shared (ACER, 2020) and are further elaborated in Section 2.7. The Commission's 2025 report states that adherence to these rules as well as evidence of the fact that cross-border participation is technically possible are key elements in its analysis of proportionality and distortions for the internal market (European Commission, 2025).

Another significant aspect in terms of compatibility is the level and duration of support, contract duration, de-rating factors and review and cessation provisions. The EU scheme does not require a standard contract length, but Commission (2025) emphasises that long-term contracts must only be used to offset new investment risks. De-rating factors, which transform the installed capacity into reliable capacity for remuneration purposes, capture the likelihood of different technologies being present in stress events and are interrelated with the parameters and methodologies adopted into the ERAA (European Commission, 2025). The Commission also assesses whether schemes are subject to review clauses and sunset or adjustment mechanisms that could enable capacity mechanisms to be adjusted or phased out in case adequacy improves or if market reforms eliminate the market failures (European Commission, 2025).

In terms of State aid, all these components are subject to the compatibility criteria laid down in the CEEAG. Security of supply is considered as an objective of common interest, but capacity mechanisms have to be necessary and proportionate for this objective and not cause any undue negative impact on competition and trade (European Commission, 2022). In practice, the Commission assesses for each notified scheme if the reliability standard and adequacy assessment concerns justifies that level of capacity procurement, if the design of the measure minimises costs and distortions (price signals, incentives as close as possible) and if it will ensure cross-border participation objectives in an environmentally friendly way or on a technological neutral basis (European Commission, 2025).

Overall, the EU design standards and compatibility conditions limit the design choices for capacity mechanisms. Although Member States have discretion to opt for a range of models, such as market-wide capacity markets and strategic reserves, they must do so within a framework that builds on competitive procurement processes, non-discrimination and cross-border integration as well as on environmental alignment and proportionality.

2.7 Cross-border participation

A particular concern in the context of the EU framework is that national capacity mechanisms do not jeopardise the functioning of the internal electricity market or lead to unjustified disparities between Member States in terms of security of supply. Cross-border participation is thus a core design aspect of capacity mechanisms. Pursuant to Article 26 of Regulation (EU) 2019/943, Member States implementing capacity mechanisms are required to accept participation by foreign capacity providers on a non-discriminatory basis with limited exceptions in case of certain strategic reserves. The rationale is that adequacy is not national but regional and capacity mechanisms should be able to access the most competitive resources across borders to achieve efficiencies and market integration. According to ACER's 2024 monitoring report on security of supply this obligation is underpinned by the broader objective to make adequacy measures consistent with the principles of the internal market (ACER, 2024).

To implement Article 26 of Regulation (EU) 2019/943, ACER adopted in 2020 the technical specifications for cross-border participation in capacity mechanisms. These rules lay down in detail a methodology for the calculation of MEC available to foreign participation, certain provisions regarding common rules for availability checks and non-availability payments and the running of a register of eligible providers of foreign capacity together with common methods for finding such capacity (ACER, 2020). Technical requirements state that reaching the coexistence of all capacity mechanisms and allowing participation across borders will enable selection on the basis of cost-efficient capacity resources, ensure non-discriminatory competition between providers regardless the geographic location and encourage cross-border regional cooperation (ACER, 2020).

One central component of this scheme is the MEC calculation. It is necessary for Regional Cooperation Centres (RCCs) to determine the maximum quantity of foreign capacity that can be counted as reliable towards ensuring adequacy between bordering areas in each delivery year per Member State system basis (ACER, 2020). This calculation shall be coherent with the ERAA approach considering estimated interconnection availabilities, the expected concurrence of system stress in the concerned bidding zones and total available capacity resource margin (ACER, 2020). In addition, the technical specifications define how allocation revenues of this entry capacity are to be distributed between TSOs, how checks on availability of foreign capacity should be performed by foreign TSOs, when non-availability payments shall occur and what is the modus operandi of a common register for foreign providers (ACER, 2020). Theoretically, this structure should create fair treatment between foreign and domestic capacity suppliers. The aim is not to distort cross-border trade or create rents for the domestic resource but to facilitate the efficiency of capacity mechanisms and their complementarity with respect to the internal market (ACER, 2020).

The 2024 EU electricity security of supply report from ACER offers a real view of implementation. It points out that by 2023 only a subset of capacity mechanisms had facilitated direct foreign participation under the technical specifications and that even when it is theoretically possible for foreign capacity to participate, so far volumes in which foreign capacity has been contracted were modest (ACER, 2024). Furthermore, ACER (2024) continues that cross-border participation has not yet been fully implemented and that further effort is required to exploit the potential provided by contributions from other countries. The 2025 Assessment of the European Commission for possibilities to simplify procedures in order to accelerate capacity mechanisms approval states that indeed cross-border participation is among the most difficult features within the existing set-up. It cites that the Member States often see obligations linked to cross-border participation, such as the need to match ERAA results, negotiate and conclude detailed TSOs agreements, or set up registries and monitoring systems, as administrative burdens and time-consuming (European Commission, 2025). Even if the Commission stresses that cross-border participation is indispensable for avoiding distortions and making sure capacity mechanisms do not undermine the internal market, it acknowledges that the current explicit participation model brings a considerable degree of complexity to design and approval of capacity mechanisms (European Commission, 2025).

This evaluation is reiterated and extended in the policy brief by Menegatti and Meeus (2024). According to the authors, post 2024 electricity market design reform capacity mechanisms have been nurtured as an element of structural design of the market, but they are still designed and operated nationally which leads to cross-border externalities that cannot be efficiently internalised by any type of cross-border participation (Menegatti and Meeus, 2024). Specifically, they single out explicit cross-border participation according to the current legislation as being particularly cumbersome and suggest in the short run relaxing this requirement and replacing it with its implicit version via market coupling, which comes at lower implementation costs but might offer similar results in terms of recognising cross-border contributions (Menegatti and Meeus, 2024). More long-term, they require thoughts about more European solutions to national capacity mechanisms since in an integrated electricity market such national measures are bound to present issues regarding fairness and sharing of burden that cannot be settled through purely bilateral agreements (Menegatti and Meeus, 2024).

2.8 State aid notification and approval practice

Outside the specific sectoral rules of the Electricity Regulation, capacity mechanisms amount to undertaking remuneration from State resources and therefore constitute State aid within the meaning of Article 107 TFEU. Accordingly, they need to be firstly notified and approved by the European Commission. The Commission's analysis is based on the general State aid framework and CEEAG and considers these rules consistently with the sectoral provisions of Regulation (EU) 2019/943 and the related resource adequacy framework. The Commission's 2025 assessment of possibilities for simplifying the procedures to grant quicker approvals for capacity mechanisms points out that the Electricity Regulation and the CEEAG jointly shape the analytical framework against which compatibility under Article 107 TFEU ought to be examined (European Commission, 2025).

As a matter of procedure, the confirmation of capacity mechanisms generally follows a standard flow that is initiated with prenotification contacts between the Member State and the Commission (European Commission, 2025). At this stage, the Commission and the notifying authorities engage in discussions with respect to the capacity mechanism, its relationship with implementation plan under Article 20 of Regulation (EU) 2019/943 and adequacy assessments and isolated design features that could raise questions on compatibility. According to the European Commission's report (2025) the pre-notification discussions may be extensive and iterative, especially for new or complex schemes, and are an important milestone that can decrease objections at notification stage.

Once the mechanism is sufficiently designed, a Member State serves an official notification under the rules on State aid. In such a case, the Commission follows standard practice and tests the capacity mechanism against compatibility criteria (European Commission, 2022). In this regard, after several evaluation phases, the Commission confirms that the State aid achieves an objective for the public-interest, which is security of supply and then assesses whether there is a proven market deficiency as described in Section 2.5. Furthermore, the Commission reviews whether implementation plan is necessary and appropriate as described in Section 2.5 and whether proportionality is followed in accordance with CEEAG. The report of the European Commission (2025) emphasises that having an implementation plan and clear evidence of progress in its execution is a key aspect to show that the capacity mechanism is not used as a substitute for market reforms.

The 2025 Commission's report provides some real-world experience in implementing this approval process. It recognises that both Member States and the Commission had a learning curve in the early implementation of the framework. The integration of technical content, including ERAA based assessments of adequacy, reliability standards and implementation plans with the existing State aid procedures resulted in particularly long pre-notification phases which were also very resource intensive (European Commission, 2025). On average, the formal adoption of a capacity mechanism takes six months or more from notification, and in some cases discussions with Member States have also taken more than two years (European Commission, 2025). Member States have expressed concerns with the administrative burden, lack of predictability and the time needed to receive a decision, notably where capacity mechanisms were perceived as urgent responses to imminent adequacy risks (European Commission, 2025).

At the same time, the Commission (2025) notes that this initial complexity was instrumental for practices to converge and for decisions to be grounded on a more solid analytical base. The growing reliance on common methodologies in the context of reliability standards and adequacy assessments, the phased approach noted to the cross-border participation framework and publication of detailed decisions have provided greater predictability and legal certainty for Member States and investors. Yet the Commission (2025) acknowledges that, especially in an increasingly decarbonised system where capacity mechanisms are likely to play a more structural role, current processes can still be challenging and that there is scope for simplifying the assessment of capacity mechanisms.

2.9 Streamlining capacity mechanisms

The experience gained with the adoption of capacity mechanisms under the framework after 2019 as well as Member States' concerns in terms of administrative burden and timing, prompted co-legislators during the market design reform to request the Commission to streamline and accelerate assessment of such schemes. Regulation (EU) 2024/1747 requires the Commission to assess the operation of the current rules on capacity mechanisms and identify options for simplification under Chapter IV of Regulation (EU) 2019/943 while respecting its basic principles such as necessity, proportionality, technology-neutrality, cross-border integration and environmental compatibility.

Addressing this, the Commission's 2025 assessment of the possibilities for simplification to accelerate approval of capacity mechanisms summarises the experience with previous State aid decisions and presents a more predictable method under which notifications will be assessed in the future. A key aspect is the establishment of standard models applicable to capacity mechanisms which concern market-wide auction-based capacity markets and strategic reserves (European Commission, 2025). For schemes that substantially match these standard designs and are supported by adequacy assessments under ERAA, the Commission anticipates simplified procedures including abbreviated pre-notification periods and fast State aid approvals (European Commission, 2025).

Commission also defines certain technical aspects to ensure consistency and standardisation. These include greater clarity and transparency of ERAA as the reference adequacy assessment, better alignment of how VoLL, CONE and reliability standards are estimated and made publicly available at a national level and more consistent handling of de-rating factors and comparable treatment of new technologies (including storage or demand response) (European Commission, 2025). The Commission (2025) foresees that a large proportion of notifications will be evaluated against existing benchmarks, thereby reducing case-specific disagreements over methodology.

These insights have already been incorporated in the Clean Industrial State Aid Framework (CISAF), which was adopted as part of the clean industrial deal in 2025. CISAF (2025) provides target models for market-wide capacity mechanisms and strategic reserves with key design features such as competitive auctions, technology-neutral eligibility within transparent decarbonisation constraints, arrangements for cross-border participation, contract lengths and penalty regimes. CISAF (2025) therefore presents the design of such capacity mechanisms in a more explicit manner with internal-market rules, the EU's decarbonisation path and an aim to enhance investment predictability.

The evolving outline of the framework thus necessarily points to a future where most European capacity mechanisms will be within a few standardised design categories, evaluated under simplified processes and based on common adequacy and parameter methodologies.

2.10 Thesis implications

The EU regulatory and State aid framework define the operation of capacity mechanisms. EU framework promotes consistency among Member States by setting certain design requirements as far as capacity mechanisms are concerned and Member States are obliged to use a common methodology for reliability standard based mainly on ERAA. The 2024 market design reform and the recent CISAF demonstrate that capacity mechanisms are no longer considered a last resort, but they are structural tools that can be used long-term. Security of supply affects significantly the competitiveness of the EU internal electricity market and is interrelated with affordability and decarbonisation (Aurora Energy Research, 2025). To this extent, the policy for energy adequacy, including capacity mechanisms, is considered as one of the key elements to address the energy trilemma. Considering the aforementioned developments, the thesis aims to analyse the capacity mechanisms based on the current EU regulatory and State aid framework, ERAA principles and the recent design simplifications introduced by the Commission.

The literature reviewed in Section 2 shows that there is a well-established framework for adequacy policy in the EU including energy-only market aspects, the missing-money problem, capacity mechanisms design, adequacy and State aid processes. Nevertheless, certain important issues remain unsettled concerning the cost-effectiveness of different designs, the appropriate balance between national and regional mechanisms, the alignment of capacity mechanisms with decarbonisation objectives and their role in a future capacity-dominated market design. The thesis contributes to this discussion by considering this institutional and theoretical background with an empirical cross-country analysis of wholesale price volatility and capacity costs and with a simple Cournot model of a capacity-dominated market design and by setting forward-looking questions on the design and governance of a capacity-dominated EU market architecture.

3. Research methods

The thesis combined a cross-country quantitative analysis with a theoretical model of capacity mechanisms aiming to identify the main features that are going to define the role of capacity mechanisms in a future capacity-dominated market architecture. The empirical part was performed using a cross-sectional dataset of European countries focusing on capacity mechanisms, price volatility and some selected structural characteristics of the power system. A Cournot model was then applied for a discussion about the prospective capacity-dominated market design following Motta's equations (2004) and how such a market would function in the context of imperfect competition and changing adequacy perceptions.

3.1 Data sources

The research analysis was performed using information about EU countries from the sources below:

- Security of EU electricity supply monitoring reports published by ACER in 2024 and 2025 including information on capacity mechanism type, capacity revenues, auction clearing prices, cross-border MEC, security of supply measures, adequacy metrics and System Average Interruption Duration Index (SAIDI).
- Electricity country sheets monitoring data published by ACER in 2025 for the year 2024, providing a range of relevant indicators for the retail electricity markets in EU Member States, including concentration ratios for household and non-household segments, the number of hours in a year with wholesale electricity prices below 5 €/MWh or above 150 €/MWh, the average daily spread €/MWh, the number of days in a year during which the difference between the highest and lowest hourly electricity prices exceeded 50€/MWh, the share of electricity generated from renewable energy sources (RES) in the country's total electricity production.
- A 2024 analysis of European capacity markets by Aurora Energy Research, used to collect data regarding the split between thermal and renewable/flexible resources for capacity mechanism payments.
- World Bank population figures, used to calculate per capita indicators by dividing total annual capacity mechanism costs for each country by the resident populations of the countries.

Countries were also included in the sample as long as they provided data to all preceding variables and this information was coherent across these sources. To this extent, Iceland was omitted from regression analysis since major variables were not available. Thus, 27 countries were used in descriptive analysis whereas 26 countries in regression analysis.

3.2 Variable definition

The following measures were used as volatility indicators on a country's level:

- Hours with prices below 5 €/MWh (LP5): Refers to the number of hours in a year during which wholesale electricity market prices fell below 5€ per megawatt-hour and includes negative prices. High hours typically suggest high renewable generation and low consumer demand introducing the need for greater consumer flexibility and storage capacity (ACER, 2025).

- Hours with prices above 150 €/MWh (HP150): Refers to the number of hours in a year during which wholesale electricity market prices exceeded 150€ per megawatt-hour. High hours indicate limitation on supply or reliance on expensive generation having a direct impact on consumer bills and market volatility (ACER, 2025).

- Days with price fluctuations > 50 €/MWh: Refers to the number of days in a year during which the hourly spread exceeded 50€/MWh. This indicator captures the extent of intraday price volatility and indicates issues in balancing supply and demand as well as the value of flexible assets (ACER, 2025).
- Average daily spread (€/MWh): Defined as the average of maximum minus minimum hourly wholesale electricity prices across all days in the year. It gives a sense of the daily price volatility and the value that may be realised by moving consumption or generation within day (ACER, 2025).

For the econometric analysis, the average daily spread was employed as a key continuous measure of price volatility, while HP150 as a measure for frequency of extreme price spikes.

The status of capacity mechanisms and related security of supply measures is coded as:

- CM_any: A dummy equals to 1 if countries operate any capacity mechanism and zero otherwise.
- CM_type: a categorical variable applied in descriptive tables indicating the type of capacity mechanism (i.e. market-wide central buyer, market-wide decentralised obligation, strategic reserve and no capacity mechanism).
- Flex_dummy: takes value 1 if in the ACER a presence of flexibility related measures was reported (for example demand-response schemes or backup reserve capacity) and 0 otherwise.
- Other_dummy: an indicator variable takes a value of 1 if other security of supply measures were in place (such as non-standard ancillary services, retention of existing generation or emergency schemes) and zero otherwise.
- Number of security of supply measures (SoS_measures): a dummy for the number of distinct security of supply measures per country, counted according to ACER classification. This variable was additionally used to stratify the countries into three groups (0–1 measure, 2 measures, or ≥3 measures) in the descriptive analysis.

For countries with market-wide mechanisms, the following additional variables were constructed:

- Share_thermal and Share_RES_flex: share of total capacity mechanism payments paid to thermal technologies and RES according to Aurora research sources.
- CM_cost_total: annual cost of the capacity mechanism in 2024 (million euros) reported by ACER.
- CM_cost_per_capita: CM_cost_total divided by the resident population in euros per person.

Furthermore, the following key elements have been used:

- RES_generation: share of renewables in total electricity generation (percentage) as per ACER country sheets

- HHI_retail and HHI_non_retail: Herfindahl–Hirschman indices for the concentration of retail and non-retail sectors of the electricity industry, as provided by ACER.
- SAIDI: System Average Interruption Duration Index, an indicator of reliability at a distribution level, expressed in hours per customer per year.
- Reliability standard: the reliability standard established in expected hours of loss of load per year, thus a measure of the necessary level of security of supply.
- VoLL: value of lost load in €/MWh that denotes the maximum electricity price that customers are willing to pay to avoid an outage (European Parliament and Council, 2019).
- CONE: cost of new entry for the reference technology in each capacity mechanism, in €/MW·year and type of the corresponding reference technology (e.g. OCGT, demand response, renewal and prolongation), presenting the total annual net revenue per unit that a new capacity resource would need to receive over its economic lifetime in order to recover its capital costs and annual fixed costs (European Parliament and Council, 2019).

These variables were utilised descriptively to reflect preferences for national adequacy and in order to interpret the Cournot model.

For countries with market-wide auctions enabling foreign participation, data on MEC were used. Specifically:

- MEC_TSO: the maximum level of cross-border capacity that is allowed to participate in the capacity mechanism by the TSO.
- MEC_RCC: the maximum cross-border capacity deemed accepted by the RCC.
- Procured: actual cross-border capacity procured.

Furthermore, two additional measures were calculated to evaluate how current capacity mechanisms make use of cross-border capacity:

- TSO_RCC_gap: the relative difference between the maximum level of cross-border capacity that is allowed to participate by TSO (MEC_TSO) and the maximum cross-border capacity deemed accepted by the Regional Coordination Centre (MEC_RCC), defined as (MEC_TSO – MEC_RCC) / MEC_RCC
- Use_ratio: calculation of the procured cross-border capacity divided by the maximum level of cross-border capacity that is allowed to participate by TSO (MEC_TSO).

3.3 Regression analysis specification

The regression analysis was performed for two models using the Ordinary Least Squares (OLS) method with country level observations.

In the first model, the dependent variable was the average daily spread (Spread_i).

$$\boxed{\text{Spread}_i = \alpha + \beta_1\text{CM\_any}_i + \beta_2\text{RES\_generation}_i + \beta_3\text{Flex\_dummy}_i + \beta_4\text{Other\_dummy}_i + \beta_5\text{Number of SoS\_measures}_i + \beta_6\text{HHI retail}_i + u_i} \quad (1)$$

where i denotes countries and u_i is the error term.

The first model tested whether a capacity mechanism in place had an impact on average daily spread, controlling for the presence of renewable penetration, the presence of flexibility and other measures, the number of security of supply measures and concentration in retail markets. It should be noted that HHI retail was included because retail concentration can influence how wholesale price movements are passed to final customers since in more concentrated retail markets suppliers could be able to absorb short-term price fluctuations whereas in more competitive markets suppliers may be more exposed to spot prices. HHI non-retail was not included due to the specialised bilateral contracts in place making this index a weaker proxy. For this reason, HHI retail was used to incorporate the competitive and regulatory environment on the demand side.

In the second model, the dependent variable was the number of hours in a year during which wholesale electricity market prices exceeded 150€/MWh ($HP150_i$), keeping all the independent variables the same:

$$\boxed{HP150_i = \alpha + \beta_1 CM\_any_i + \beta_2 RES\_generation_i + \beta_3 Flex\_dummy_i + \beta_4 Other\_dummy_i + \beta_5 Number\ of\ SoS\_measures_i + \beta_6 HHI\ retail_i + u_i} \tag{2}$$

The regressions were computed using the regression function in Microsoft Excel. Given the small sample (26 countries), the simple structure of the models and the analysis is primarily exploratory focusing on cross-country associations, a basic OLS estimator was sufficient to obtain transparent coefficient estimates and significance tests without the need for more complex econometric techniques. Standard errors were estimated as usual under OLS assumptions. It should be highlighted that given the small sample size and that information is in cross-section the results are interpreted as evidence of association rather than estimates of causality.

Regarding the expected coefficient signs the following should be noted. The capacity mechanism dummy (CM_any) was expected to have a negative coefficient given that capacity mechanisms are designed to address non-availability risks and thus market volatility. The RES_generation variable was anticipated to be negatively related to the average daily spread since higher renewable penetration generally lowers average prices and compresses spreads, while its relationship with the HP150 variable was ambiguous. Flex_dummy, Other_dummy and Number of SoS_measures variables were expected to have negative coefficients as they are intended to mitigate security of supply risks. However, no clear sign was imposed ex-ante to HHI_retail variable given that its contribution is affected by market conditions and regulatory arrangements.

3.4 Cournot capacity model

A simple Cournot model considering a capacity mechanism was built in line with a linear Cournot set-up as can be found in Motta (2004).

Assuming that $n \geq 2$ firms were symmetric in the model and that each firm i selected a capacity quantity $k_i \geq 0$ in MW to offer into the capacity mechanism.

The total capacity contracted was:

$$K = \sum_{i=1}^{n} \mathrm{k}_i \tag{3}$$

The capacity price p^C was set by the inverse linear demand function:

$$p^c(K) = \alpha - \beta K \tag{4}$$

in which $\alpha > 0$ is the intercept and depicts the marginal willingness to pay for the first MW of firm's capacity and $\beta > 0$ is the slope of the demand curve.

Each firm has an annual constant cost c per MW of capacity, which was interpreted as the CONE of a representative marginal resource.

Profit was given by:

$$\pi_i = (p^c(K) - c)\, k_i = (\alpha - \beta K - c)\, k_i \tag{5}$$

At the same time, firms chose k_i taking their rivals' choices as given.

The Cournot equilibrium was derived analytically (see appendix B), and it was compared to the competitive benchmark where capacity is procured up until $p^c = c$.

The summarised model assumptions are presented below:

Table 1: Main assumptions of the Cournot model

Element	Assumption
Market structure	A finite number of symmetric firms ($n \geq 2$). Each firm i chooses a capacity quantity ki ≥ 0 in MW to offer into the capacity mechanism
Product and time frame	A homogeneous capacity product (firm capacity for one delivery year).
Demand	The capacity price is determined by the inverse linear demand function: $p^c = \alpha - \beta K$. The parameter α represents the value of marginal additional adequacy, given a particular reliability standard and VoLL and β the marginal value of adequacy as more capacity is procured.
Cost structure	Each firm has an annual constant cost c per MW of capacity, which is interpreted as the CONE of a representative marginal resource.
Equilibrium	Firms chose ki simultaneously and non-cooperatively, taking their rivals choices as given. The outcome is a Nash equilibrium in quantities, and the competitive benchmark is defined by the condition $p^c = c$.
Adequacy	Adequacy is embedded in the shape of the capacity demand curve reflecting the chosen reliability standard and VoLL.
Policy	The model abstracts from detailed auction rules and network constraints as it is used qualitatively to illustrate how capacity prices and procured quantities respond to changes in the valuation of adequacy and in market concentration, holding c and β fixed.

Afterwards the model was normalised by taking $c = 1$ and $\beta = 1$ in order to present certain numeric figures. Specifically, two different values of α/c ratio were used, representing low and high assessments of adequacy and four different values of the number of firms representing low and high concentrated energy market. The equilibrium prices and capacity levels were considered in Section 5 in order to qualitatively examine how adequacy choices, market concentration, and capacity-price mark-ups are interacted in a capacity-dominated market architecture.

3.5 ERAA 2024 adequacy maps and capacity mechanisms map

The LOLE maps of ERAA 2024 Executive Report (ENTSO-E, 2025) presented for the years 2028 and 2030 were utilised to locate regions that could be more susceptible to electricity adequacy risks. Furthermore, security of EU electricity supply monitoring report published by ACER in 2025 was utilised to identify the current and future capacity mechanisms in individual Member States.

These two elements were considered in Section 5 to investigate whether, when and where capacity mechanisms developed seemed consistent with the adequacy risks identified by ERAA.

3.6 Limitations

The research method mainly combines cross-sectional descriptive analysis, regression analysis and a Cournot model. Although the approach is adequate to examine cross-country patterns and to generate policy-relevant outputs there are certain limitations regarding inference. Chapter 5.7 elaborates on such limitations and future work.

4. Research results

4.1 Price dynamics

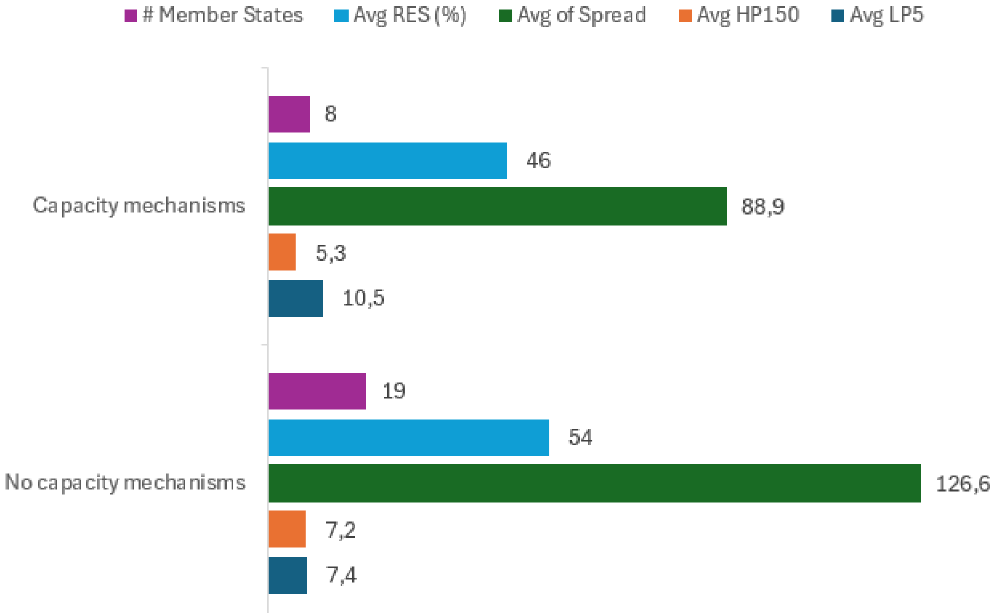


Figure 2: Volatility in countries with and without capacity mechanisms

Source: Appendix A

Figure 2 displays simple averages of the main volatility measures by country with and without a capacity mechanism. Countries not having a capacity mechanism have on average 7,2 hours with prices above 150 €/MWh and an average daily spread of about 126,6 €/MWh. Countries with a capacity mechanism, on the other hand, show less high price hours (5,3) and an average daily spread of 88,9 €/MWh. Descriptively, the existence of a capacity mechanism is correlated with less frequent extreme high prices and a smaller daily spread.

The picture is mixed when it comes to low price hours. The presence of the capacity mechanism seems to be associated with a higher share of hours whose prices are lower than 5 €/MWh (10,5) on average in countries with capacity payments (7,4 in countries with no capacity mechanism), even though their mean value of renewable penetration is somewhat lower (46% compared to 54%). This comparison suggests that low price events are not limited to systems with very high RES share but could also be indicative of the wider market and policy design in countries where there is a capacity mechanism.

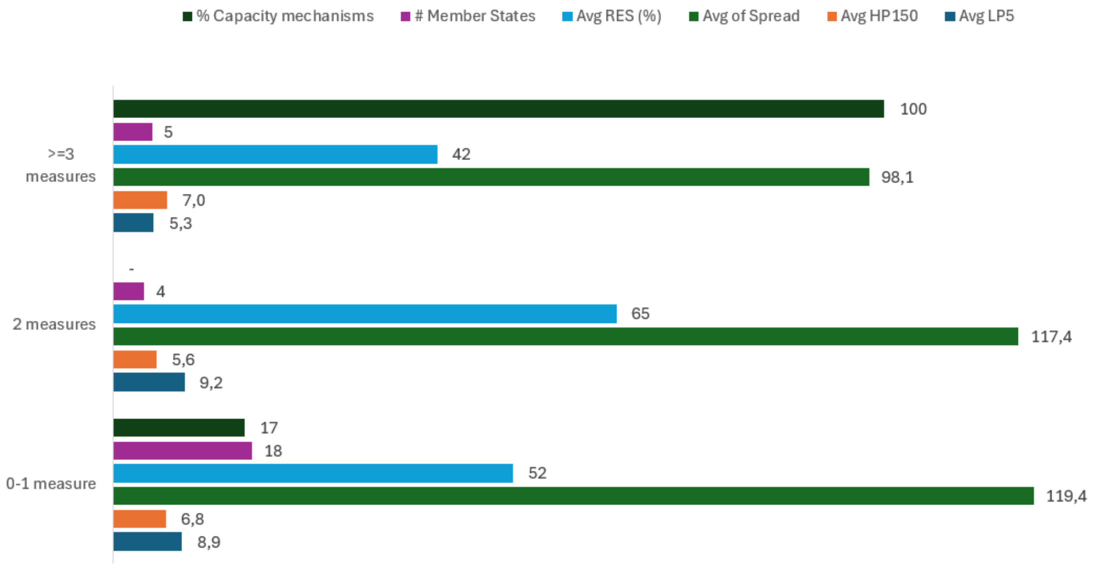


Figure 3: Number of security of supply measures and volatility

Source: Appendix A

Figure 3 clusters representative Member States based on the number of security of supply measures as identified by ACER and compares important market-related figures of these two groups. Countries with no or one security of supply measure are spreading an average daily spread of about 119,4 €/MWh and about 6,8 of hours above 150 €/MWh. The spread is extremely similar in systems with two measures (117,4 €/MWh) and somewhat fewer hours at high prices (5,6). By comparison, countries with 3 or more security of supply measures have a substantially lower average daily spread (98,1€/MWh) compared to the other two groupings (around 117–119 €/MWh) but also a lower proportion of very low price hours, on average showing 5,3 hours versus roughly 9 for the other groups. The number of high price hours (7,0) is just above the two-measure group (5,6) and similar to the 0–1 measure group (6,8). At face value, systems with 3 or more measures are linked to a smaller daily range of prices but not systematically to less extreme price peaks or more often near-zero prices.

However, the composition of these groups suggest that this finding is not directly interpretable as a causal effect from more measures to greater improvement. Countries using 3 or more measures have a capacity mechanism and the average share of RES is only slightly lower (42%). The two-measure group in contrast has the highest on average share of RES (65%) and includes no capacity mechanisms at all, while the 0–1 measure group is dominated by energy-only systems (only 17% have a capacity mechanism).

4.2 Regression analysis

Regression analysis considers 26 countries (excluding Iceland) in a single-year cross-section and is intended to explore associations rather than causal relationships:

$$\text{Spread}_i = \alpha + \beta_1 \text{CM\_any}_i + \beta_2 \text{RES\_generation}_i + \beta_3 \text{Flex\_dummy}_i + \beta_4 \text{Other\_dummy}_i + \beta_5 \text{Number of SoS\_measures}_i + \beta_6 \text{HHI retail}_i + u_i \tag{1}$$

$$\text{HP150}_i = \alpha + \beta_1 \text{CM\_any}_i + \beta_2 \text{RES\_generation}_i + \beta_3 \text{Flex\_dummy}_i + \beta_4 \text{Other\_dummy}_i + \beta_5 \text{Number of SoS\_measures}_i + \beta_6 \text{HHI retail}_i + u_i \tag{2}$$

Table 2: Regression analysis results

Parameters	**(1) Average daily spread (€/MWh)**	**(2) Hours with price >150 €/MWh**
CM_any	-64,59 (29,18)**	-5,86 (3,82)
RES generation (%)	-0,68 (0,35)*	-0,05 (0,05)
Flex_dummy	-2,89 (24,69)	-1,31 (3,23)
Other_dummy	-45,68 (34,55)	-4,32 (4,52)
Number of SoS measures	25,65 (23,99)	3,16 (3,14)
HHI retail	0,0026 (0,0032)	0,00023 (0,00041)
Constant	147,12 (27,29)***	8,66 (3,57)**
R²	0,55	0,28
Adjusted R²	0,40	0,05
Observations	26	26

*** p < 0,01, ** p < 0,05, * p < 0,10

- Dependent variable in equation (1) is the average daily wholesale price spread (€/MWh).
- Dependent variable in equation (2) is the percentage of hours with prices above 150 €/MWh.
- Standard errors are in parentheses.

Table 2 presents the OLS regression results with average daily spread as the dependent variable and a series of structural and policy variables as regressors. The model (1) accounts for about 55 percent of the cross-section variation in the average daily spread (R² = 0,55, adjusted R² = 0,40), and the joint F-test suggests that the regressors are statistically significant as a group (p=0,01). The coefficient on capacity mechanism is -64,6 €/MWh (standard error 29,2, p < 0,05) thus negative and statistically significant controlling for RES penetration, the flexibility schemes, the wider patchwork of security of supply measures and retail market concentration. Therefore, countries with a capacity mechanism have around 65 €/MWh lower daily spread rather than those that do not have. However, as the regression is conducted on a single-year cross-section of 26 countries eight of which have in place a capacity mechanism, the size of -65 €/MWh needs to be considered as illustrative rather than precisely reflecting the impact of capacity mechanisms on price volatility. Nonetheless, the negative and statistically significant estimate is in accordance with the descriptive evidence and indicates a materially strong association between the presence of a capacity mechanism and lower average daily spread.

The coefficient on renewable share is also negative (-0,68) and marginally significant at the 90% confidence level (standard error 0,35, p<0,10) meaning that a one percentage point increase in RES share is associated with a decrease of about 0,7 €/MWh on the daily spread. For this straightforward specification high RES penetration is therefore only slightly associated with lower spreads, considered capacity mechanisms and structural factors are being held constant. By contrast, the dummies for flexibility schemes, other security of supply measures, number of measures as well as retail HHI are statistically insignificant with relatively imprecise estimates which are highly sensitive to specification.

Overall, column (1) shows that capacity mechanisms and to a lesser extent RES penetration were found to be the main variables associated with a lower value of observed average daily spread across Member States. As a robustness check, the regression was re-estimated excluding Norway, which is an outlier (z-score=2) with very low average daily spread. The results remained unchanged with adjusted R^2 fell slightly to 0,33 while the capacity mechanism dummy remained negative (-63 €/MWh) and statistically significant (standard deviation=28,9, $p<0{,}05$). Other parameters remain insignificant, including RES penetration. The robustness check therefore supports the conclusion that the negative association of capacity mechanisms which average daily spread is stable and not driven by an exclusion of an outlier.

A second model displayed in column (2) makes use of the fraction of hours in which 150 €/MWh price level is used as dependent variable. Unlike the findings related to the daily spread, this regression is not a good fit since the R^2 is 0,28, adjusted R^2 only accounts for 0,05 and the joint F-test does not reject H0 that all coefficients are zero (p=0,34). None of the component regressors are statistically significant at a 95% confidence level. The coefficient on the capacity-mechanism dummy is negative (-5,90) indicating that countries with a capacity mechanism tend to have fewer very high-price hours than energy-only countries, but it is imprecisely estimated and does not even reach statistical significance at the 90% confidence level (standard error=3,8, p=0,14). Also, the estimated impacts of RES penetration, flexibility schemes, additional security of supply measures and retail concentration are small and statistically not different from zero.

A correlation matrix (Appendix B) shows no severe multicollinearity, although the number of security of supply measures is strongly correlated with the Other_dummy and to a lesser extent with the existence of a capacity mechanism. This overlap is consistent with the relatively large standard errors on these coefficients in the regressions.

In this cross-section the policy and structural variables that have been picked do not therefore robustly work on explaining the frequency of extreme price spikes, which might be due to other factors such as fuel mix, interconnection, weather patterns, or idiosyncratic events. Furthermore, given the small sample size and that information is in cross-section the results are interpreted as evidence of association rather than estimates of causality.

4.3 Capacity mechanisms in practice

Figure 4: Technology composition of capacity mechanisms

Source: Appendix A

Figure 4 summarises for the Member States operating with capacity mechanisms, the allocation of capacity payments between thermal versus RES and flexible resources, the relevant reliability standard and selected indicators (i.e. SAIDI and country RES generation). Thermal technologies consistently receive the greatest share of capacity payments in all countries with 63% thermal in France, 66% in Poland, 84% in Italy and more than 70% in Ireland and Belgium. It is also noted that the RES penetration of capacity mechanisms is not systematically aligned with the decarbonisation progress of the Member State. In particular, Italy and Ireland have 49% and 46% RES share in generation respectively, yet they spend only 12% and 18% of capacity mechanisms on RES and flexibility. In contrast, Belgium and Poland which have more moderate RES share at 34% and 31% allocate around 30% of their capacity mechanism support on RES and flexibility and thus are closer to their RES share in the energy mix. France falls in between with 27% of both RES generation and capacity contribution. The applied reliability standard is also highly similar across countries with just some variety from 2 to 3 hours/year. However, this apparent alignment in adequacy criteria is combined with a very divergent mix of capacity mechanisms which emphasises that the reliability standard dictates how much capacity to procure but it does not drive the type of technology. Additionally, there is also no consistent correlation between composition of capacity mechanisms and the value of SAIDI which is between 0.67 in Belgium to 3.46 in Poland given that the reliability in the distribution is mainly affected by network investment and quality of service regulation and seems to be largely independent with whether capacity remuneration flows more toward thermal or low-carbon technologies. Overall, it can be shown that the current capacity mechanisms achieve their adequacy objective using mainly portfolios of fossil technologies even in countries where there is a high RES generation.

Table 3: Capacity mechanisms costs

Country	2024 costs to finance CMs (million euros)	Average Spread (€/MWh)	Average of Population (in millions)	Cost per capita (€)

France	2.670	77	68,516699	39
Germany	81	112	83,51095	1
Ireland	466	100	5,380257	86,6
Italy	1.797	80	58,986023	30,5
Poland	1.412	121	36,554707	38,6
Sweden	7	46	10,569709	0,7

Source: Appendix A

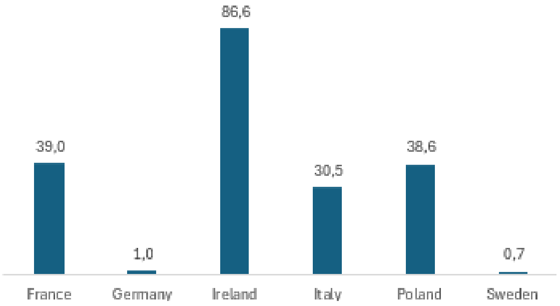


Figure 5: Capacity mechanisms cost per capita (in €)

Source: Appendix A

Figure 5 shows that costs of capacity mechanisms per person vary significantly across Member States. Sweden has a cost per capita below €1, Germany's cost per capita amounts to €1, Italy to €30 per person, France and Poland to around €39 while Ireland's cost rises significantly to nearly €87 per person. These deviations highlight the capacity mechanisms differentiation in terms of size and design. Specifically, Germany and Sweden possess smaller and more targeted strategic reserves, France, Italy and Poland manage large market-wide schemes with substantial payment volumes whereas Ireland has a small population affecting significantly the cost per capita.

The comparison of these figures to average daily wholesale spread in Table 3 does not exhibit any incremental relationship between capacity payments and stability. By contrast, Sweden combines the lowest per capita level of capacity mechanism expenditure (~€0,7) with by far the smallest spread (€46/MWh), which reflects its hydro-dominated and well-interconnected structure as well as the small size of its strategic reserve. At the other end of the spectrum, Poland and Ireland share high spreads (€121/MWh and €100/MWh) despite paying relatively high per capita capacity mechanism costs (~€39 and ~€87 respectively), which indicates that in less decarbonised or tightly supplied settings large capacity payments do not invariably mean low wholesale volatility. Between them, France and Italy have a medium spread (~€77-80/MWh) and per capita costs ranging from €30 to €39 confirming the earlier regression result that countries with a capacity mechanism are more likely to have a lower price range while also illustrating that this stabilising mechanism can occur at widely different cost levels.

In general, the per capita perspective emphasises that the financial burden of capacity mechanisms on final consumers is highly heterogeneous across Member States, and it is not a matter of clear proportionality when compared to what was observed in terms of reduced volatility. This reinforces the idea that when designing capacity mechanisms, today and tomorrow's administrators should consider not only adequacy and price-stabilisation effects but also impact of alternative designs on cost-effectiveness and distribution.

Table 4: Cross-sectional analysis

Country	Capacity mechanism status	NRAA	CONE fixed technology	CONE fixed EUR/MW	2024 costs to finance CM (million euros)
Belgium	Market-wide - central buyer	yes	demand response	30.000	-
Finland	Strategic reserves	yes	renewal & prolongation	17.000	-
France	Market-wide - decentralised obligation	yes	demand response	60.000	2.670
Germany	Strategic reserves	yes	demand response/open cycle gas turbine	2.072 & 57.067/23.377	81
Ireland	Market-wide - central buyer	yes	open cycle gas turbine	115.990	466
Italy	Market-wide - central buyer	yes	open cycle gas turbine	53.000	1.797
Poland	Market-wide - central buyer	no	demand response/open cycle gas turbine	30.183/119.256	1.412
Sweden	Strategic reserves	yes	demand response	10.068	7

Country	Capacity revenue, EUR/MW for delivery year 2024	Market-wide capacity auction clearing prices, delivery year 2025	Share_ thermal (%)	Share-RES (%)	SAIDI 2023
Belgium		15.695	73	27	0,67
Finland		-			0,88
France	28.151	102.002	63	27	2,18
Germany		-			0,21
Ireland		147.580	77	18	1,76
Italy	39.207	45.000	84	12	1,65
Poland	64.135	196.408	66	32	3,46
Sweden		-			1,05

Country	Reliability Standard h/year	Single VOLL EUR/MWh	Average Spread (€/MWh)	RES generation (%)	Population (in millions)
Belgium	3	12.832	92,38	34	11,88
Finland	2,1	8.000	81,91	56	5,64
France	2	33.000	77,05	27	68,52
Germany	2,77	12.240	112,08	57	83,51
Ireland	3	17.909	99,78	46	5,38
Italy	3	20.000	80,41	49	58,99
Poland	3	17.173	121,25	31	36,55
Sweden	1	7.065	46,49	70	10,57

Source: Appendix A

As a complement to this cross-sectional approach, this subsection presents a brief description of the eight Member States which have a capacity mechanism in place (Belgium, Finland, France, Germany, Ireland, Italy, Poland and Sweden).

A first difference is made between market-wide capacity mechanisms and strategic reserves. As already stated, market-wide mechanisms have been introduced in Belgium, France, Ireland, Italy and Poland while Finland, Germany and Sweden operate strategic reserves. In 2024, France, Italy and Poland invested between €1,4 to 2,7 billion each on their mechanisms, while Ireland invested approximately €0,47 million. In comparison, Germany annual cost of strategic reserves was around €81 million and €7million in Sweden. Capacity revenues and auction clearing prices are calculated only for the market-wide schemes and vary significantly. For instance, France and Italy exhibit intermediate auction clearing prices while Poland records the highest among others.

Regarding adequacy criteria, the reliability standard and the VoLL are the two parameters which are especially relevant for the design of capacity mechanisms. The reliability standard specifies the level of adequacy in probabilistic terms in which supply is permitted to fall short and in most EU systems it is the expected number of hours per year that demand cannot be fully met (ACER, 2020). A 3 hours/year standard, for example, means that the system is designed to result in failure to meet demand for not more than 3 hours per year on average over many years. This benchmark is then transformed into a firm capacity requirement based on adequacy modelling and in practice sets the amount of capacity that must be secured through the capacity mechanism. In countries with a capacity mechanism the reliability standard is quite homogeneous since most of them aim for around 3 hours year, while France has a slightly tighter standard (2 hours/yr) with Sweden having an even tighter standard at 1 hour/yr.

By contrast, VoLL is an economic metric and defines the amount of money that users are willing to pay to avoid one unserved megawatt-hour of electricity. Specifically, it represents an average of all damages from the loss of one MWh of load including lost production, discomfort, and other social costs. The reliability standard should be defined in principle at a level at which the marginal cost of obtaining additional capacity equals the expected benefit from a decrease in unserved energy. In practice, however, Member States apply different methodologies and assumptions leading to widely differing values of VoLL. Indicatively, Finland and Sweden have relatively low VoLL values (around 7.000–8.000 €/MWh), followed by Belgium and Germany with intermediate values (around 12.000–13.000 €/MWh), whereas Ireland, Italy and Poland have high estimates (approximately 17.000–20.000 €/MWh or more) with France having the highest value (33.000 €/MWh). Such differences suggest different national VoLL tolerances whereby a higher VoLL indicates a greater willingness to pay for avoiding outages and, in principle, warrants more capacity investment or higher scarcity prices. The existence of reliability standards that are broadly similar but associated with VoLL levels and capacity mechanism designs which differ significantly demonstrates the persistence of different implicit trade-offs between cost and security of supply among Member States which entail a further reason preventing the full harmonisation of adequacy rules and design of capacity mechanisms.

In addition to the reliability standard and the VoLL, a third significant parameter is the CONE. CONE is the capital cost of an efficient marginal capacity resource and it is annualised in €/MW·year. Typically, it is calculated based on the annualised upfront capital and fixed operating costs of a reference technology and defines the demand curve in the capacity auction in market-wide capacity markets (ACER, 2020). To this extent, the price at which the market clears when the system is at the target reliability standard should be around CONE with the new entry of the reference type be able to recover fixed costs based on revenues from capacity with no great reliance on energy market scarcity rents (ACER, 2020).

Table 4 indicates that the reference technology selected for CONE and the assigned values vary significantly among the Member States. Belgium and France both specify CONE as a function of demand response and CONE is set at around €30.000/MW·year and €60.000/MW·year respectively. In Ireland and Italy an open-cycle gas turbine (OCGT) is used as CONE technology with corresponding CONE estimates of about €115.990 and €53.000/MW·year respectively. Poland has both demand response and OCGT with CONE values of €30.183/MW·year and €119.256/MW·year for demand response and OCGT. Regarding strategic-reserve countries, CONE in Finland is estimated at approximately €17.000/MW·year based explicitly on renewal and prolongation of existing units while in Sweden the marginal technology is demand response with a rather low CONE of about €10.068/MW·year. Germany uses demand response and OCGT with different levels of costs. This diversity reflects the divergent perspectives on which a resource (new thermal capacity, demand response, life-extended existing plant) is predictable to become marginal in the long-run, indicating already a lack of harmonisation in the conceptualisation of new entry across the EU internal electricity market.

To further illustrate the heterogeneity of design choices and market conditions, actual auction clearing prices can be compared to these CONE benchmarks. Compared to the demand-response CONE of €30.000/MW·year, the 2025 capacity-auction clearing price in Belgium is comfortably low (about €15.695/MW·year), indicating that the capacity mechanism is compensating only existing resources rather than indicating the need for new investment. Italy follows a similar trend with the clearing price of approximately €45.000/MW·year being a little under OCGT−based CONE of €53.000/MW·year again consistent with a situation in which the capacity mechanism mainly serves to top up revenues of an existing resource. However, France's clearing price, which is approximately €102.002/MW·year, is well above its demand-response CONE of €60.000/MW·year and more consistent with peaking capacity being needed given tighter adequacy margins identified in national assessments. Results in Ireland and Poland are even more obvious given that their clearing prices (roughly €147,580 and €196.408/MW·year respectively) are significantly above at least one of their reported CONE values, suggesting either that the market jointly identifies capacity to be in short supply and/or that the design intentionally permits high capacity prices.

In total, the CONE evidence supports the conclusion reached more generally from the reliability-standard and VoLL analysis. There is also no agreed benchmark for the CONE nor consistent correspondence between that benchmark and observed capacity prices even among Member States that have adopted capacity mechanisms under a common EU framework. Some capacity mechanisms result in a clearing price that clears systematically below CONE, redistributing revenue among existing resources and others at or above CONE, indicating persistent scarcity or a policy choice to support new capacity. Together with the diverse VoLL assumptions and adequacy issues that have arisen, this heterogeneity in CONE levels and reference technologies highlight the extent to which national preferences and legacy system characteristics remain important drivers of capacity mechanism design. It also brings into reality one of the main challenges to any capacity-dominated market architecture, that of how to reconcile adequacy targets, risk preferences and investment signals between Member States to better support security of supply and decarbonisation while avoiding unnecessary internal market distortions.

Last, the SAIDI demonstrates no natural correlation across capacity mechanism designs. SAIDI, in contrast to adequacy indicators which are based on probabilistic modelling of system-wide capacity shortfalls, is an ex-post performance indicator that reflects the duration over which customers genuinely lose supply owing to faults, weather events, maintenance or localised network constraints (World Bank, 2025). Countries with a capacity mechanism differ, with a very low SAIDI values in Germany (around 0.2 hours/customer/year) and Belgium (0.7 hours) to rather higher ones in Poland (3.5 hours), where also Finland, France, Ireland, Italy and Sweden fall in between (about 0.9–2.2 hours). These discrepancies mostly arise from system-wide historical investments in their distribution networks, grid topology, exposure to weather and quality of service regulation, rather than from the existence or specific design of capacity mechanisms. No relationship emerged between SAIDI and technology mix or cost of capacity mechanisms. Poland has the highest SAIDI and the largest and relatively expensive market-wide mechanism in the sample, while Germany and Belgium combine very low SAIDI with a strategic reserve and a more modest capacity mechanism respectively. This also reinstates the fact that capacity mechanisms mainly address generation adequacy as well as price dynamics while end-user reliability indicators, as expressed by SAIDI, depend primarily on network regulation and investment decisions, thus only to an indirect extent reflecting capacity mechanism architecture.

To this extent, the existing EU capacity mechanisms are very heterogeneous along the factors of instrument type, technology mix, VoLL assumptions, cost levels and consistency with adequacy assessments. As presented, both market-wide capacity mechanisms and strategic reserves can serve to reduce price dispersion but have very different budgetary and distributional implications. However, the significant diversity among capacity mechanisms can explain why the Commission and ACER embarked on target model definition and expedited approval processes in order to reduce administrative burden and minimise the risk of a fragmented set of national specific solutions which could lead potentially to distortions to competition and decarbonisation objectives.

Table 5: Cross-border data for 2026

Country	MEC TSO, MW for delivery year 2026	MEC RCC, MW for delivery year 2026	Procured, MW for delivery year 2026	TSO_RCC_gap	Use_ratio
Belgium	1.260	2.210	1.260	-0,43	1,00
France	10.200	4.812	9.040	1,12	0,89
Italy	4.365	-	4.365	0,00	1,00
Poland	1.527	453	1.539	2,37	1,01

Source: Appendix A

Cross-border data for 2026 presented at Table 5 reveal that capacity mechanisms standalone continue to utilise foreign resources in a limited and inconsistent manner across all markets. Auction results in countries having a defined MEC as set by the TSO, are nearly always saturated indicating a positive demand from market participants for cross-border participation. Thus, the actual constraint is the MEC value that the TSO sets and which, in some cases (e.g. Belgium) lies well below the capacity that the RCC assessments would permit or well above with respect to France and Poland. These patterns are in line with ACER's (2025) finding that the sizing of the mechanisms by Member States does not yet integrate all the contribution potential that neighbouring resources may have and that at TSO/RCC level there is not yet full alignment regarding the methodologies to assess the cross-border adequacy levels. Overall, the conservative use of MEC volumes set by TSOs suggests that cross-border participation is not fully incorporated yet in adequacy provision despite the existing EU framework in place.

4.4 Cournot capacity model

The following Cournot model is used in this subsection to illustrate the behavior of a future capacity-dominated market design in the presence of imperfect competition. This model is based on the Cournot model (Motta, 2004) re-expressed in terms of capacity.

There are $n \geq 2$ symmetric firms. Firm i chooses $k_i \geq 0$ (MW) of firm capacity to offer into a capacity mechanism. Total contracting capacity amount is

$$K = \sum_{i=1}^{n} \mathrm{k}_i \tag{3}$$

There is a linear inverse demand function that determines the capacity price p^c:

$$p^c(K) = \alpha - \beta K \ , \ \alpha > 0 \ , \ \beta > 0 \tag{4}$$

Profit of the firm i's from the capacity mechanism is:

$$\pi_i = (p^c(K) - c)\, k_i = (\alpha - \beta K - c)\, k_i \tag{5}$$

Parameters refer as follows:

- α: maximum willingness to pay for the first MW of reliable capacity. Conceptually, it represents the value of marginal additional adequacy, given a particular reliability standard and VoLL.

- β: slope of the capacity demand. Higher β means that willingness to pay declines more rapidly as additional capacity is procured representing the diminishing marginal value of adequacy.
- c: constant annual cost of capacity per MW, being the CONE of a representative marginal resource.

Firms select k_i simultaneously taking rivals choices as given. The resulting symmetric Cournot equilibrium is (see Appendix B for more information):

$$k^* = \frac{a - c}{\beta\ (n + 1)} \tag{6}$$

$$K^* = \frac{n(a - c)}{\beta\ (n + 1)} \tag{7}$$

$$p^{C*} = a - \beta K^* \ = \frac{\alpha + nc}{n + 1} \tag{8}$$

In comparison, at the competitive benchmark $p^c = c$ is satisfied, such that capacity in total is:

$$K^{comp} = \frac{a - c}{\beta} \tag{9}$$

This implies two relationships:

$$\frac{K^*}{K^{comp}} = \frac{n}{n + 1} \tag{10}$$

$$p^{C*} - c = \frac{\alpha - c}{n + 1} \tag{11}$$

In Cournot competition, capacity is under-procured compared to the competitive objective by the ratio $\frac{n}{n+1}$ and the price of capacity is excessive relative to cost by a mark-up which increases with α (maximum willingness to pay) and decreases with n (the number of effective competitors).

For a purely illustrative calibration, the model is normalised by setting c=1, β=1. Therefore, all prices are given in units of CONE and all capacities in arbitrary units.

It should be noted that the parameter α in the Cournot model is neither the reliability standard itself nor the VoLL in €/MWh. Instead, α corresponds to the amount individuals would be willing to pay for an additional MW of reliable capacity. This willingness depends on the assumed reliability standard and VoLL although the Cournot model applied here does not contain a full adequacy curve or Monte-Carlo features. The model used simply introduces values for the ratio α/c to ease representation of low or high adequacy valuations while preserving some degree of qualitative nature. It is worth mentioning that α has to be higher than c, as otherwise the competitive level of capacity would not exist and no capacity procurement would occur according to the model.

For the numerical illustrations two values of α/c ratio are considered:

- α/c=1,5 for a low adequacy valuation slightly above cost;
- α/c=3 for a high adequacy valuation, reflecting the case in which the marginal benefit of increased reliability significantly exceeds the cost for entering new capacity.

These can be interpreted as transitioning from a case of capacity just paying for itself, through one in which society is willing to buy at a significant cost premium without necessarily specifying precise quantitative relationships with given national standards.

The level of competition is expressed in terms of the number of firms n.

The following four scenarios are examined:

- Scenario A: Few firms, low adequacy value | n=3, α/c=1,5
- Scenario B: Few firms, high adequacy value | n=3, α/c=3
- Scenario C: Many firms, low adequacy value | n=8, α/c=1,5
- Scenario D: Intermediate number of firms, high adequacy value | n=5, α/c=3

For c=β=1, the competitive benchmark capacity becomes:

$$K^{comp} = \alpha - 1 \tag{12}$$

and the Cournot price is:

$$p^{C*} = \frac{\alpha + n}{n+1} \tag{13}$$

Table 6: Cournot outcomes with low and high adequacy valuations

Scenario	**n**	**α/c**	**K^{comp}=α−1**	$\frac{K^*}{K^{comp}}$	K^*	p^{C*}/c	**Mark-up** $p^{C*}/c - 1$
A – Few firms, low adequacy	3	1,5	0,50	0,75	0,375	1,125	+12,5 %
B – Few firms, high adequacy	3	3,0	2,00	0,75	1,50	1,50	+50,0 %
C – Many firms, low adequacy	8	1,5	0,50	0,889	0,444	1,056	+5,6 %
D – More firms, high adequacy	5	3,0	2,00	0,833	1,667	1,333	+33,3 %

Table 6 shows that:

- In the case of three firms and a low adequacy valuation (Scenario A) the capacity mechanism only procures 75% of the competitive benchmark at a modest 12,5 % mark-up over CONE.

- Increasing the adequacy valuation from 1,5 to 3 (Scenario B) increases also capacity from 0,375 to 1,50 units but increases additionally the mark-up by 50 % above CONE.
- Leaving the low adequacy as in Scenario A but increasing the number of firms from 3 to 8 (Scenario C) causes the mark-up to drop towards about 5,6% while capacity rises near the competitive levels (89 % of benchmark).
- Scenario D shows that with a high adequacy assessment it is possible to reduce the mark-up from 50% to 33% and the level of capacity towards an amount close to 83% of its competitive value by increasing participation from 3 to 5 firms.

4.5 ERAA 2024 adequacy maps

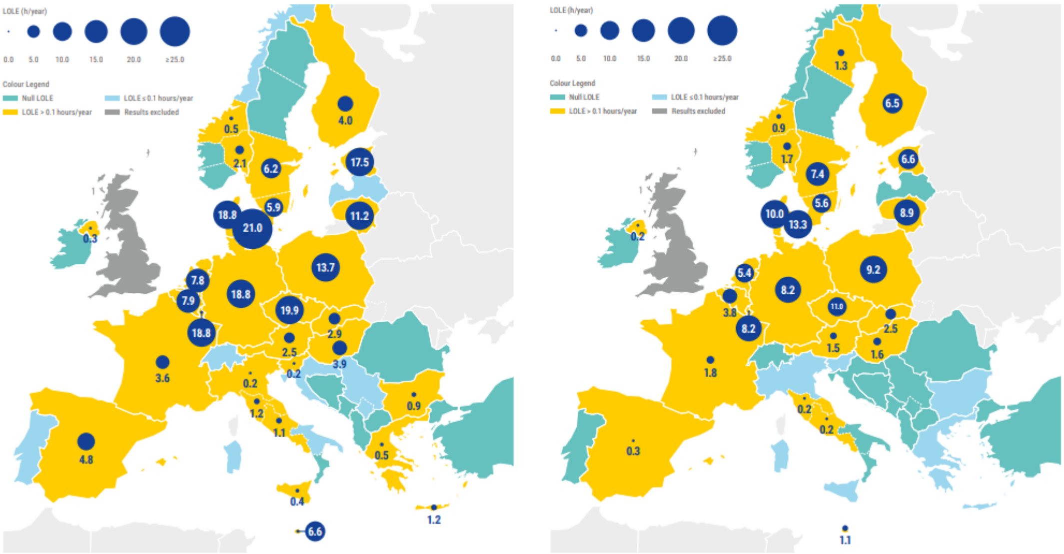


Figure 6: Adequacy risks in 2028 (left) and 2030 (right)

Source: ERAA 2024 Executive Report

Figure 6 contains maps of long-term average LOLE for years 2028 and 2030. Three categories are considered: areas with zero LOLE, those with LOLE≤ 0,1 hours/year and those with LOLE > 0,1 hours/year. These simulations already consider existing non-market resources (i.e. approved capacity mechanisms/strategic reserves).

In 2028 and 2030 many bidding zones in Central and Western Europe, some of them also part of Central and Eastern Europe, as well certain Nordic and Baltic areas have positive LOLE values, often higher than 0,1 hours/year. Others, such as the vast majority of Balkan systems and a few Western European zones have zero LoLE. For the period 2028-2030, LOLE levels rise in some zones and decrease in others, reflecting planned investments and policy measures already included in ERAA.

The 2025 ACER Security of EU electricity supply Monitoring Report contains a map that presents an overview of existing and prospective capacity mechanisms in the EU and neighbouring countries (Figure 1). Apart from the existing capacity mechanisms which have been already covered, the same figure shows the target years for bringing additional capacity mechanisms in place. For instance, Spain is in advanced stage of preparation and Estonia considers introducing a strategic reserve by 2027. The map also notes the expiration of some existing approvals between 2031-2035 based on State aid rules.

The aforementioned figures present a forward-looking perspective on the adequacy risk in terms of LOLE and expected roll-out and reform in capacity mechanisms that will be used as inputs in Section 5.

5. Research Discussions

Chapter 5 is linked to the three research questions set out in the Introduction. First, as far as the evolution of the energy-only markets and the emergence of capacity mechanisms are concerned, the literature review demonstrated that capacity mechanisms are institutional responses to the missing-money problem in liberalised systems with large amortised incumbent fleets and have progressively shifted from last-resort instruments to structural elements of the EU adequacy and State aid framework. Second, the cross-country empirical analysis showed that capacity mechanisms are systemically associated with a narrower average daily spread, their costs vary across Member States and illustrate heterogeneous VoLL and CONE adequacy parameters across EU countries while other security of supply measures do not have clear associations with price volatility. Third, the Cournot model and the research results suggest that in a capacity-dominated market design effective governance of adequacy, regional coordination and sufficient integration of flexibility and decarbonisation objectives will be essential principles to support security of supply, affordability and decarbonisation.

As renewables make up a larger share of generation and short-run marginal costs of generation decline, the prominence of energy-only markets as the primary price formation mechanism may gradually recede. In a deeply decarbonised system over the next 15-20 years, wholesale energy prices are expected to be low for most hours with relatively rare scarcity events. This limits the scope of fixed costs recovery and consequently weakens investment signals from the energy-only market. Therefore, the core economic issue of financing and coordinating sufficient and flexible capacity is expected to be addressed through the capacity mechanisms. Within a capacity-dominated market design, spot prices would increasingly reflect the production and network costs of real-time balancing energy while long-term investment signals would be provided mainly through capacity mechanisms. However, a capacity-dominated market design is desirable only if it is embedded in a robust governance framework for adeuqacy, enforces strict decarbonisation constraints and flexibility, ensures effective regional integration and cross-border participation.

5.1 Empirical findings and implications

The descriptive evidence in Chapter 4 indicates that the presence of capacity mechanisms is consistently linked with lower wholesale price volatility among Member States. Countries lacking a capacity mechanism on average have higher daily spread (about 127 €/MWh) and a higher share of hours with prices above 150 €/MWh than countries implementing either market-wide or strategic reserve mechanisms, which show an average value for spread of approximately 89 €/MWh and fewer hours with such high prices. Meanwhile, countries with capacity mechanisms have also a lower RES share compared to countries with no capacity mechanisms so the reduction of volatility cannot be explained through higher penetration of renewable resources only.

This is also supported by the performed regression analysis. For the specification with average daily spread as dependent variable, the R^2 indicates that the model accounts for about 40–55 percent of the cross-country variation and that regressors are jointly significant. When with a certain RES penetration, retail concentration and the more general security of supply policy mix are controlled for, the capacity mechanism dummy is negative and statistically significant. The coefficient on the RES share is also negative and marginally significant at the 90% confidence level, indicating that countries with higher renewable shares are weakly related to lower spreads when the presence of a capacity mechanism is considered. In contrast, the flexibility schemes measures, other security of supply measures and retail HHI are not statistically significant, indicating that they have only a limited association with price dispersion in this specification.

However, when the dependent variable is the proportion of hours whose prices were over 150 €/MWh its explanatory power as a model falls dramatically. The R^2 drops to 0,28 (adjusted R^2 is close to zero), the joint F-test no longer rejects the null that all regressors are equal to zero and none of the individual coefficients is statistically significant. The capacity mechanism dummy stays negative, but the estimate is imprecise and statistic difference from zero cannot be proven. The impact of RES penetration, flexibility provision schemes, other security of supply measures and retail concentration is small and also not significant.

To this extent, capacity mechanisms are associated with a significantly narrower average wholesale spread even after accounting for renewable penetration and basic structural factors, with higher RES generation appearing to strengthen this relationship. In contrast, the incidence of extremely high price spikes is only weakly associated with these factors in existing cross-section and probably affected by further variables like fuel mix, interconnection patterns, weather conditions as well as short-run policy interventions. It should be noted that due to the entirely cross-section characteristics of this data and its relatively small number of observations, these associations should be viewed as correlations rather causal effects. The empirical results thus provide support for the argument that current capacity mechanisms have the ability to contribute to a stabilisation of price dynamics in the EU internal electricity market as far as the average daily spread is concerned, but they also illustrate inherent limitations in established designs and data for controlling extreme price risk which is a central concern in the future debate over future capacity-dominated market designs.

The practical implications of the empirical evidence for the wider research question of this thesis, whether and how capacity mechanisms can be an effective instrument in response to security of supply and energy transition challenges in the EU internal electricity market are manifold.

First, the relation between capacity mechanisms and reduced price dispersion indicates that capacity mechanisms can address the security and affordability aspects of the energy trilemma. They can also help limit risk for investors as well as consumer volatility by shrinking the daily spread. At the same time, the weak impact on extreme price spikes suggests that capacity mechanisms alone may not be able to stabilise prices completely, not in response to exogenous shocks in particular. To this extent, other measures such as scarcity pricing, hedging markets, network reinforcement and flexibility procurement are still needed.

Second, today's technology mix in capacity mechanisms demonstrates that capacity mechanisms are not necessarily compatible with decarbonisation objectives. In many cases, a significant proportion of capacity payments is allocated to fossil-fuel sources, even when RES are already important in the generation mix of countries. If eligibility criteria, auction parameters and carbon constraints are not stringent enough there is a risk that capacity mechanisms will lock in high-emitting technologies, complicating transition to a system largely focused on low-carbon capacity and increasing its costs. In this respect, current capacity mechanisms address the security and affordability aspects of the trilemma, with their contribution to decarbonisation though being relatively modest and very design specific.

Third, the variety of adequacy parameters, cost values and cross-border MECs shows that there is not yet a single integrated capacity market in the EU. Rather, today's mechanisms represent national risk preferences and inherited generation systems. Indeed, the recent policy initiatives (i.e. EU electricity market design reform, CISAF with fast-track approval of capacity mechanisms for target models) can be interpreted as efforts to address this diversity. A subset of the descriptive evidence in this thesis, considering the dispersion of CONE, VoLL and cross-border utilisation, supports the rationale that there is potentially high room for increasing cost-effectiveness, carbon performance consistency and cross-border integration when it comes to how capacity mechanisms are designed.

Lastly, considering that in the foreseeable future most assets will be paid for their capacity value, the empirical results show both threats and opportunities. On the one hand, the fact that capacity mechanisms are found associated with less spread in prices and given that market participants are willing for foreign capacity wherever allowed suggests in principle that a capacity-dominated design could establish secure investment signals and facilitate regional sharing of adequacy resources. Conversely, the use of fossil-intensive capacity schemes and the large spread in CONE, VoLL and MEC estimates caution that it would be hazardous to assume a straight scaling-up from today's capacity mechanisms will necessarily result in a sustainable integrated capacity-dominated system. Rather, any move to such a framework will have to explicitly co-optimise adequacy and flexibility, introduce strict carbon limits and introduce more harmonised regional frameworks for the valuation of cross-border capacity, as further elaborated in the following subsections.

All in all, the empirical evidence shows that capacity mechanisms have already become a core component of EU response to the security of supply challenge associated with the energy transition. However, their contribution to the energy trilemma is still partial and uneven and significant design and governance innovations will be necessary if future capacity market designs aim to reliably support security of supply, affordability and decarbonisation.

5.2 ERAA 2024 adequacy maps interpretation

ERAA 2024 provides a harmonised probabilistic perspective of adequacy in Europe. Figure 6, as presented in the ERAA Executive Report, shows maps for average LOLE, both for 2028 and 2030. The maps demonstrate that adequacy risks are pervasive but also quite heterogeneous. Central and Eastern Europe, some Nordics and selected Baltic systems have LOLE values in the range of several hours per year by 2028-2030, while risks are low in the Balkans. This is further evidence that concerns for adequacy in a decarbonising Europe are systemic rather than simply an isolated instance experienced regionally.

An observation arises upon comparison of the ERAA maps with the 2025 ACER Security of EU electricity supply Monitoring Report (Figure 1) that shows the timing for introduction and redesign of capacity mechanisms. ACER's figure indicates that several Member States will in fact introduce new capacity mechanisms or significantly change existing ones just around the late 2020s-early2030s. Specifically, Spain is in advance preparation for a capacity mechanism, Italy and Poland plan to perform changes in their schemes by 2028, Estonia considers introducing a strategic reserve by 2027, while the Czech Republic introduced some firm capacity mechanism rules into its legislation. This clustering in time echoes ERAA's depiction of 2028 and 2030 as years of concern for adequacy (ENTSO-E, 2025), while the acceleration of renewable deployment combined with thermal decommissioning and electrification results in LOLE to be greater than 0,1 across many zones if no additional capacity is added. The developing pipeline of capacity mechanism projects can, therefore, be interpreted as a policy reaction to the midterm adequacy risk identified within ERAA rather than as an isolated national trend.

It should be noted that the LOLE values in Figure 6 are residual risks after taking into account currently contracted out of market resources. According to the ERAA approach, contracts concluded in the context of approved capacity mechanisms are accounted for as available capacity, hence any residual LOLE means that under the central scenario existing schemes are not enough to address all expected shortages. As such, residual LOLE points towards the necessity of changing the scale or design of capacity mechanisms. Furthermore, the uncertainty about scarcity revenues and interconnector performance in stress events is underlined in ERAA (ENTSO-E, 2025) which diminishes the extent to which energy-only markets can be considered as a dedicated solution.

These ERAA-derived findings provide an interpretation for the results presented in Chapter 4. The cross-sectional comparison of Member States with and without capacity mechanisms revealed that countries with capacity mechanisms have lower average price spreads but a considerable cost per capita, varying widely from one to another. A number of the countries cited in ERAA with residual LOLE values in 2030 are those with capacity mechanisms already or soon to be operational. However, systems with lower LOLE and a high level of interconnection have instead been focused mainly on energy-only markets. This consistency of projected adequacy risks with the geography of the existing and planned capacity mechanisms strengthens the view that capacity mechanisms are responses directed at structural adequacy problems.

5.3 Interpretation of Cournot model results

The Cournot model results presented in Chapter 4 provide support for three qualitative aspects. The first insight is that the more stringent the adequacy target (higher α/c) is, the higher is the equilibrium capacity price and the mark-up over CONE when competitors are few. Second, intensity of competition is an important factor in aligning prices and quantities as the increase of firms leads to the capacity competitive benchmark lowering mark-up over CONE. Third, a future capacity-dominated market design will require properly calibrated adequacy parameters (reliability standard and VoLL) as well as sufficient effective contribution (including cross-border resources, storage and demand response) to prevent excessive mark-ups on prices for a given level of capacity.

As already stated, the parameter a in the Cournot model represents the maximum willingness to pay for the first MW of reliable capacity. To this extent there are the following interpretations for the demand intercept α:

- A higher reliability standard or larger VoLL implies that there is an increased willingness to pay for an additional amount of reliable capacity which corresponds to a higher α.
- On the other hand, less constrained reliability standard or lower VoLL results in a smaller marginal value of capacity and thus reduces α.

The model does not aim at replicating the detailed ERAA or ACER estimations relating to reliability standard, VoLL and CONE nor the full Monte-Carlo adequacy simulations. Instead, it takes α as a proxy for how tight the adequacy standard is and how valuable an extra MW of capacity is, while c integrates the cost element through CONE. The interpretations of Table 6, thus, are used as comparisons across systems with different mixtures of reliability standard/VoLL (via α/c) and level of competition (via n), keeping the CONE stable.

The empirical analysis contained in this thesis demonstrates that in the present hybrid EU arrangement capacity mechanisms already play a non-negligible role both in securing adequacy and reallocating risk among consumers, generators and states. Meanwhile the Cournot model can be a useful way of systematically dealing with how capacity systems might operate going forward. This subsection uses the research results to draw qualitative insights for policy and future capacity mechanisms design.

As already stated, in a future capacity-dominated market investment signals will be covered mainly through capacity mechanisms and all resources will balance at capacity level. In the Cournot model, this is represented by the fact that companies' profits only depend on the capacity price and on the capacity amount. As demonstrated in the Cournot equilibrium the capacity price is affected by the adequacy standards and the CONE. To this extent, the proper price signal of capacity price is critical given that in a capacity driven regime there will not be an alternative market to correct price signals.

The Cournot equilibrium further implies that, in the absence of extremely competitive capacity markets, the price of capacity will tend to be driven systematically above its CONE. As demonstrated, assuming the marginal value of capacity α is greater than its cost c, equilibrium mark-up over cost is equal to $p^{C*} - c = \frac{\alpha - c}{n+1}$ (11) and prices clear above the CONE, provided that there is a finite number of active firms.

The examples presented in Table 6 demonstrate mark-up sensitivity based on the market structure and adequacy standards. For three symmetric firms and a tight adequacy valuation the model generates mark-ups on the order of 50 % above CONE. Mark-ups are in the range of 10-15 % where a few firms compete with a low adequacy valuation. When competitors increase with a low adequacy valuation, however, the mark-up drops into single digits and capacity is close to the competitive benchmark.

The result is to be understood as a warning in future systems where capacity is the main driver of investment and where many Member States will probably have a few number of large portfolios integrating dispatchable plants as well as storage and demand response. Even if the reliability standard is correctly chosen, concentrated capacity markets will tend to set prices that remain above any reasonable estimate of CONE. From a policy standpoint, these mean that regulators cannot simply set an adequacy target and expect a capacity mechanism to meet it at cost. The proper degree of concentration, combined with the particular auction design (pay-as-cleared, pay-as-bid, demand-curve slope, minimum participation requirements etc.), will ultimately determine the cost level of capacity payments. Thus, the cost of security of supply is being co-determined by adequacy choices and market structure assumptions.

This is a critical aspect given the current debate in the EU regarding security of supply. The inherent need to treat security of supply as a public good correlated with competitiveness and autonomy may incentivise Member States to have more conservative reliability standards. As demonstrated using the Cournot model such choices will lead to increased capacity prices, especially where markets are concentrated. Thus, the challenge is to find a balance between higher adequacy needs and reasonable costs of capacity mechanisms by expanding for instance the effective participation in capacity auctions.

Finally, the number of competitors plays a significant role as demonstrated in the Cournot model. As the competition is intensified firms operate closer to the competitive capacity benchmark by reducing concurrently the relevant mark-up. In a future EU capacity-dominated market, the number of firms does not include only the national incumbents but rather domestic generators, storage operations, demand-response aggregators and cross-border resources. To this extent, the model gives theoretical support to recent EU initiatives that seek to reinforce cross-border participation by simplifying approval processes and by removing entry barriers so that new technologies can be integrated better into capacity mechanisms. This also relates to the research results in this thesis that where cross-border MECs are followed then auctions utilise them fully, indicating the foreign capacity demand is not a limitation.

Considering that in the future capacity prices will be the principal signal of adequacy and policy choices will lead to higher reliability, then the broad participation in capacity auctions will be a pre-condition to ensure reasonable capacity prices. Thus, it is implied that a capacity-dominated market design needs certain conditions with regard to competition, transparency and regional coordination which are further described below.

5.4 Adequacy and capacity governance framework

The research results of the thesis demonstrate that capacity mechanisms are not anymore considered exceptional last-resort measures but rather elements ensuring energy security during energy transition. In a future capacity-dominated market design the governance framework of adequacy will be critical for the successful operation of capacity markets.

One of the cornerstones of the adequacy governance framework is the methodology of VoLL, CONE and reliability standard. Under ACER's methodology each Member State is obliged to explain and publish one single estimate of VoLL and technology-specific CONE values derived from transparent and verifiable cost assumptions (ACER, 2020). Furthermore, for each reference technology, the economically optimal reliability standard is determined by settling the annualised cost of a marginal unit of capacity (CONE) with the expected value of avoided unserved energy set at VoLL (ACER, 2020), providing a common language among Member States. Hence, additional capacity is needed when the EENS times VoLL exceeds the annual fixed cost indicating that the socially optimal level of adequacy is the one at which the marginal cost of providing additional reliability is equal to its marginal social value. As demonstrated in the simplified Cournot model by increasing adequacy standards, the price of capacity mechanisms and the relevant mark-up are increased, especially when the market is concentrated, suggesting that the definition of adequacy measures is not only a matter of technical consideration but a clear trade-off regarding security of supply and affordability.

Another key aspect of the adequacy framework is the ERAA. ERAA is not a prediction of future capacity balances but rather a risk assessment with different scenarios which identifies the circumstances that may lead to inadequacy issues (ACER, 2020). ERAA 2024 presents not only a high probability of adequacy challenges in a number of regions under various decarbonisation and demand-growth scenarios but also highlights that in an energy-only market mitigating shortages through scarcity prices will not be sufficient to incentivise timely investment in capacity (ENTSO-E, 2025). Furthermore, ERAA 2024 explicitly acknowledges that capacity mechanisms and other supporting instruments can play a key role in settling the investment gap (ENTSO-E, 2025).

Additionally, following Commission's report on capacity mechanism simplification in March 2025, ENTSO-E submitted a proposal on the amended ERAA methodology on 6 November 2025 on which ACER aims to decide by February 2026. Even if the proposal is not accepted yet, there is a clear suggestion that the EU governance framework is developed. The suggested changes re-confirm ERAA as the focal point for capacity-mechanism approvals by specifying that ERAA shall cover at least the whole EU interconnected system, by clarifying that adequacy should be assessed under harmonised scenario frameworks and by tightening the connection between ERAA outputs and the parameters necessary under the Methodology for the CONE, VoLL and RS and the CISAF (ENTSO-E, 2025). The proposed methodology also places greater focus on consistency between adequacy and flexibility needs assessment noting that they cannot be treated independently (ENTSO-E, 2025). As already mentioned, even if ERAA is a sophisticated probabilistic framework, it cannot eliminate uncertainty. Instead, it can be used as a risk assessment that should be supplemented by national assessments, stress tests and careful policy judgement. Consequently, ERAA is a necessary but not sufficient condition for adequate policy to be sound.

This emerging governance framework has a cost and price dimension, which is the subject of the empirical analysis contained in this thesis. A comparison of the price evolution in Member States with and without capacity mechanisms suggests a tendency for a lower price volatility in countries with capacity mechanisms. Simultaneously, ACER monitoring reports and the evidence compiled in Chapter 4 confirm that the cost of capacity mechanisms has risen sharply over the past 10 years and both auction clearing prices and costs per capita differ significantly between Member States with generally similar reliability standards. The per capita costs indicators derived for Member States show that some countries achieve only small improvement in price volatility for a very high implicit cost, whilst others seem to provide similar adequacy results whilst carrying largely lower costs related to capacity. The aforementioned differences indicate that the governance of adequacy in a future capacity-dominated EU market cannot be limited to measures of reliability. Adequacy as well as capacity mechanism design decisions should explicitly incorporate cost-effectiveness and distributional elements. The Methodology for the CONE, VoLL and RS already mandates the publication of VoLL and CONE estimates, the disclosure of underlying assumptions (such as fuel and carbon price paths, technology costs, and the weighted average cost of capital), and the transparent estimation of the corresponding reliability standard. The draft ERAA reform steps further by connecting ERAA-based adequacy figures, reliability standard selections and capacity-mechanism designs to the CISAF target models, which are allowed a simplified and expedited State aid approval process. Collectively, this architecture is well-placed to create the potential for an EU-wide benchmark of efficient adequacy solutions since Member States who adopt the harmonised adequacy framework and the capacity mechanism target models will exploit the reduction in regulatory risk, the increased predictability and the lower CONE. By contrast, deviations from these benchmarks will require not only justification merely in technical but also in economic terms.

One additional aspect that adequacy governance will have to incorporate more explicitly is the relationship between capacity mechanisms and investment in new infrastructure. Enhanced EU planning for grid investment, as called for by the recent initiative on Energy Highways, highlights that adequacy and market integration are achievable only through timely investment in cross-border transmission and digitalisation and grid-enhancing technologies and foresees the need for a central scenario for infrastructure planning across the EU where national plans are insufficient in order to confront investment gaps

(European Commission, 2025). However, if ERAA and National Resource Adequacy Assessment (NRAA) predict a given level of cross-border capacity which is ultimately not delivered then capacity markets could procure a ‘paper adequacy’ that cannot actually be realised physically. On the other hand, properly synchronised grid expansion may lower the demand for firm capacity by allowing areas with excess flexibility or thermal capacity to assist tighter regions. The governance system for that future adequacy will therefore need to link ERAA scenarios, Ten-Year Network Development Plans and national capacity mechanism characteristics.

These developments and findings suggest three general directions for a future EU-wide adequacy and capacity governance framework. First, ERAA once revised should be the single starting point for adequacy concerns and for determining volume of capacity procurement with NRAAs used as complementary instruments when there are clear differences in assumptions about future developments, risk preferences or local constraints. Second, adequacy parameters and the design of capacity mechanisms must be regarded as direct economic policy decisions, evaluated not just on the technical metrics, but in systematic examination of their impact on capacity price, cost per capita, price volatility and competitiveness, consistent with the energy trilemma and the Clean Industrial Deal. Third, given that capacity prices will be the primary adequacy signal in an architecture that is dominated by capacity, the EU-level governance should monitor prices and compare them with ranges that are consistent with VoLL, CONE and reliability standard parameters and with competitive market outcomes, considering market structure and cross-border participation. This thesis' Cournot analysis shows that with a few competitors in a concentrated capacity market and high reliability standard, adequacy will be provided at the market price corresponding to a significant mark-up above the CONE, while a more competitive and regionally integrated capacity mechanism can provide the same degree of reliability at lower cost. Consequently, these insights must be embedded into the evolving framework at a time when the internal electricity market is set out to deliver secure, low-carbon and low-cost electricity to EU consumers and industry. Therefore, the governance decisions in the following years will be critical in deciding whether capacity mechanisms will be an enabler of or a deterrent factor to a coherent European response to energy trilemma.

5.5 Regional, coordinated and competitive capacity mechanisms

The research analysis of this thesis has demonstrated, firstly, that capacity mechanisms already constitute a significant cost to consumers and, secondly, that their effect on price volatility and adequacy is contingent on market structure, resource participation and cross-border integration. Capacity mechanisms cannot be national measures when ERAA along with national and regional adequacy assessments issue adequacy decisions. Common weather phenomena and simultaneous thermal unit retirements drive strong correlations in adequacy risks between neighbouring systems as it is shown in Central and Northern Europe in ERAA 2024 (ENTSO-E, 2025). This means national mechanisms that neglect regional interactions under-procure capacity by assuming imports that do not materialise in stress events and over-procure capacity by failing to consider firm contributions from neighbouring countries leading to the conclusion that a regional and coordinated approach is absolutely essential.

A first aspect that should be considered is the convergence of adequacy aspects. Methodology for the CONE, VoLL and RS and the ERAA framework already assume that any concerns regarding adequacy should be expressed in consistent terms by comparing modelled LOLE and EENS values with national reliability standards. Regional capacity mechanisms should further develop this architecture by requiring Member

States to apply harmonised reliability standard methodologies even if there is a differentiation in numerical targets. To this extent, this approach would enable a regional auction to procure enough capacity to the point at which the marginal increase in regional reliability measured in hours of avoided LOLE or EENS equals the marginal capacity cost valued at a regional VoLL. In particular, TSOs and RCCs would express ERAA indicators as regional demand curves for capacity for which State aid compatibility benchmarks would be provided by the CISAF and target models. This would also give a greater basis for comparing the cost-effectiveness of different regional designs, with measures of cost per capita and average daily spread such as developed in this thesis.

Second, cross-border participation should be shifted from a specialised option to a structural part of capacity mechanisms. As set out in the research analysis, various Member States with market-wide mechanisms procure cross-border capacity through MEC TSO and MEC RCC components already under the current regime. Simultaneous scarcity in neighbouring systems, internal grid bottlenecks and outages may actually limit the availability of imports during critical hours therefore ERAA states that the contribution of interconnectors under stress conditions may be lower than the nominal cross-border capacity assumed theoretically (ENTSO-E, 2025). Future regional mechanisms should therefore rely on coordination between RCCs and TSOs in order to eliminate the double counting of imports. On the one hand, conservative and cost-efficient cross-zonal reliability contributions should be defined firstly by the RCCs based on flow-based capacity calculation results and probabilistic calculations and on the other hand these results should then be translated by the national TSOs into cross-border capacity products in regional auctions.

Third, it is necessary to broaden resource participation and expand regional scale to enhance competitive nature of capacity mechanisms. The Cournot analysis of this thesis has demonstrated that for concentrated markets with only a few providers of capacity equilibrium capacity prices will systematically be above CONE when reliability standards are tight and the VoLL high. Regional auctions can help largely address these issues given that they aggregate demand from several Member States while they allow the full range of eligible resources (new and existing generation, storage, demand response and cross-border capacity) to compete equally in wholesale electricity markets. Furthermore, wide auctions dilute the market power of single entities and make it harder for national incumbents to exercise control over capacity prices. Additionally, common participation rules, certain prequalification criteria and performance requirements reduce transaction costs for investors. Significant to the Cournot model, regionalisation is arguably the most efficient way through which the effective number of competitors (n) can be expanded bringing capacity prices closer to competitive benchmarks.

Fourth, predictability in State aid control and approval procedures has to be improved and better aligned with regional schemes. CISAF sets out target designs for market-wide mechanisms and strategic reserves with a fast-track approval mechanism for designs closely aligned to these templates which could shorten the pre-notification and assessment periods. Additionally, CISAF highlights that in order to ensure alignment within the EU internal electricity market, the exploitation of regional schemes, cross-border participation, competitive allocation and technology-neutrality are essential elements. Therefore, regional capacity mechanisms design considering the target models can provide regulatory certainty to Member States along with a degree of flexibility for contract lengths and de-rating factors and can reduce risk premia for investors which affect capacity prices.

Lastly, the regional, coordinated and competitive capacity mechanisms formation interacts directly with the more general debate addressed in the thesis about whether there is a potential shift from an energy-only market towards a capacity-dominated market design. If a capacity-dominated market progressively drives long-term adequacy, then guaranteeing regional integration and competition should become a prerequisite. Without an EU-level arrangement, the result would be to re-establish, many of the same inefficiencies the liberalisation aimed to mitigate, such as conflicting signals to investors and distortions to EU trade. In contrast, regional mechanisms based on a common adequacy framework, strong cross-border capacity allocation and competitive auctions can smoothly introduce the capacity only markets whilst still being sufficiently consistent with the three energy objectives of security, affordability and decarbonisation.

5.6 Flexibility and transition-oriented design

A key insight from the policy literature and the research analysis is that European capacity mechanisms have been primarily structured as adequacy backstops with only limited consideration of the quality of flexibility that they deliver and the longer-term implications of procurement for decarbonisation goals. ERAA 2024 highlights that in a rapidly decarbonising system adequacy risks are shifting from a more generic energy shortage and becoming more focused on a relatively small number of hours characterised by low renewable penetration, stressed networks and limited cross-border support (ENTSO-E, 2025). Concurrently, more than 50 GW of new flexible gas capacity could be built by 2035, mostly running for only a few hundred hours a year, if energy-only markets are only taken into consideration (ENTSO-E 2025). This selection of less frequent extreme shortages and high emergence of peaking units with low running time hours dictates that flexibility is a key system attribute. Furthermore, the majority of capacity payments continue to be allocated to thermal technologies with renewable and flexible resources (storage and demand response) typically receiving less than 12-32%. In this context, this subsection proposes certain capacity mechanisms design principles that support flexibility and are energy transition compatible.

Most existing capacity schemes define an availability requirement in a wide peak period and effective contribution to adequacy is covered by technology-specific de-rating factors. This approach tends to advantage the conventional thermal units that are willing to offer availability for a long period even if their effective flexibility, such as ramp rate, start time or ability to correct intra-hour imbalances, is marginal. A transition-oriented design should specify capacity obligations much more narrowly considering the scarcity conditions for flexibility. This change has a methodological basis already present in ERAA 2024, which identifies the hours of scarcity and LOLE on an hourly and zonal basis and traces whether the scarcity was due to a clear demand spike, low RES output, network constraints or limited imports. These statistically identified high-risk hours allow for capacity products to be qualified for availability in these hours along with the need for ramping capability and fast activation. As a result, flexible resources like batteries, responsive demand and hybrid RES-storage plants are becoming much closer substitutes to thermal units in the capacity auction. It also enables capacity remuneration to be directed towards the specific characteristics of system stress identified in adequacy assessments instead of just targeting generic peak demand. This translates to steadily considering attributes such as duration, ramping and locational attributes following transparency and technology neutrality.

As already mentioned, ERAA estimated that in mid-2030s gas fired capacity running only a few hundreds of hours will contribute significantly to the mix. From a pure adequacy standpoint, such units are cost-effective as they supply firm capacity at low annualised cost. However, relying on fossil capacity could lead to locking in fossil technologies and high emissions. There are certain ways in which capacity mechanisms can alleviate this tension. The first is to adopt strict emissions performance standards or differentiated de-rating factors that phase down over time to reduce the competitiveness of high emitting units. Secondly, they could distinguish between contract lengths. In particular, contract length could be long with stability premium for new low-carbon flexible resources (e.g. storage, demand response, renewable hybrid plants, low-carbon thermal) and shorter (e.g. one year only contracts) for existing fossil units.

Also, the CONE should be updated regularly to take into account the cost of clean flexibility options instead of just the cost of conventional peaking plants. As long as CONE values that are used for adequacy assessments and reliability standards are still calibrated with fossil fuel technologies then both ERAA and national assessments will be more likely to select fossil as the marginal technology. Therefore, re-aligning CONE to low-carbon flexibility technologies is a precondition, otherwise even a formal neutral technology mechanism will systematically compare adequacy decisions to the cost of fossil technologies.

Demand-side response (DSR) is an important capacity resource as recognised by the EU legislation and the ERAA. Yet, the research analysis of the thesis shows that DSR participation in existing capacity mechanisms has been modest so far. Industrial and commercial consumers can provide significant flexibility but are uncertain on how their baselines will be constructed and how non-delivery will be penalised. Therefore, baseline methodologies should be standardised, transparent and support proportional penalties in order to attract participation to aggregators and large consumers. Furthermore, product duration and timing should conform to demand side circumstances. While industrial DSR may be able to deliver a large reduction over a few hours or even over a limited time window, the aggregated profile for residential DSR through smart appliances or electric vehicle charging is going to differ. Capacity products and auction clearing rules can enforce the differentiation of obligations and aggregation across portfolios instead of setting a fixed availability across extremely wide peak periods to expand the types of business models that can potentially compete in capacity auctions. Additionally, a capacity mechanism which prevents or limits participation in balancing, ancillary service or local flexibility markets would undermine the business case for DSR. On the other hand, the design of capacity mechanism which can provide revenues across markets for DSR while avoiding double counting in adequacy calculations can lead to increased volume of DSR. This is also consistent with the way ERAA treats DSR as both a capacity and a dispatch resource. Thus, clarity on the treatment of aggregated revenues could promote the integration of DSR.

The contribution of storage, particularly batteries and pumped hydro, is key in a decarbonised system with zero-emission flexibility. However, high initial capital costs, uncertain revenue streams, and complicated energy-capacity revenue interactions constitute significant challenges for the effective integration of storage. Storage should be clearly recognised as eligible capacity resource in a transition-oriented capacity mechanism design with de-rating factors and contract duration that adequately reflect their system value. Financing costs can decline with longer-term contracts for new storage investments and shorter rolling contracts may be adequate for existing pumped hydro. Storage capacity obligations should therefore be described in terms of duration capabilities that align with the patterns of scarcity observed in ERAA. Hybrid RES-storage plants could be either considered as an integrated capacity resource or separate elements (RES and storage). In both cases capacity mechanism design should not be punitive with regard to low price periods and assessment of adequacy in one market should ensure that the contribution of storage is not double counted in other markets. If designed correctly such rules can make storage become the key for flexibility.

The evolution of EU capacity mechanisms in terms of flexibility and energy transition is still at an early stage. Although they currently deliver very high adequacy values and relatively low SAIDI yet their portfolios are still largely thermal, they are not followed by all Member States and even the product definitions are very generic. In order for a proper transition pathway in the context of the periodic reviews under the Electricity Regulation and the CISAF, Member States could make a commitment to quantitative milestones for the share of capacity payments that goes to low-carbon and flexible resources. Furthermore, they could gradually tighten emissions-based de-rating factors and access long term contracts to make new fossil capacity the exception. Finally, they can incorporate in the ERAA a more precise DSR and storage modelling for the calibration of reliability standards and capacity mechanism volumes so that adequacy is co-optimised with flexibility. The enhancement of cross-border transmission and the shift to more regional resource adequacy assessments in parallel will broaden the pool of flexible resources eligible to participate in national measures.

It should be highlighted that the design of capacity mechanisms focusing on flexibility and transition does not entail a departure from the present European model. It calls for a re-focusing to procure clean, responsive and regionally co-optimised capacity. The design, if complemented with the governance framework, regional integration and competition safeguards explained in previous subsections, could be a guiding principle for a future capacity-dominated market in harmony with the EU objectives.

5.7 Limitations & further research

The forward-looking analysis constructed in Chapters 4 and 5 has certain limitations that suggest important directions for additional research. Statistically, due to the cross-sectional nature of the dataset in this thesis which encompasses few Member States and only one recent period, the associations of capacity mechanisms, prices trends and security of supply metrics found should be conceived as indicative correlations rather than causal estimates. Moreover, many features of real-world capacity auctions such as dynamic bidding, portfolio optimisation, technology-specific constraints and risk aversion are abstracted from the Cournot-type capacity model and thus should be considered as an analytic tool to demonstrate a future capacity-dominated market design rather than a quantitative forecasting tool. In terms of adequacy, ERAA 2024 and the proposed methodological updates continue to be complicated by speculation over future demand and plant retirements, interconnections and climate scenarios. Thus, the capacity-dominated architecture of market structure must be seen as an analytical hypothesis based on the state of the evidence and the trajectory of policy not as a detailed blueprint. Future work could elaborate on the research results by using panel data of capacity mechanisms over time and calibrating more detailed oligopoly or agent-based models to specific regions.

6. Conclusion

This thesis aims to analyse whether and under what circumstances capacity mechanisms can represent a well-functioning solution to security of supply and the energy transition in the EU internal electricity market. Drawing on the EU liberalisation pathway and the energy-only market concept as the default design, the analysis examined how structural characteristics of European power systems, increased integration of renewables and the emerging EU adequacy and State aid landscape played a role in facilitating an increasing role for capacity mechanisms. In its design, the thesis incorporated a qualitative review of legal, economic and policy literature with a quantitative assessment of European countries and a presentation of a simplified Cournot capacity market to present how adequacy valuations and market concentration can influence capacity prices and quantities in a capacity-dominated market.

Research analysis suggests that the presence of a capacity mechanism has a statistically significant negative association with wholesale price dispersion, even after controlling for components of the market structure including penetration of renewables. Also, the effect of renewables on the electricity price dispersion can often become weakly negative when considering capacity mechanisms, which implies that at least in the current European context a higher RES penetration does not necessarily entail higher volatility. Furthermore, thermal units continue to capture the majority of capacity payments in most capacity mechanisms while RES and flexible resources capture a minority share. Capacity costs per capita and adequacy parameters vary substantially between Member States

Cournot analysis sheds light on the consequences of a future capacity-dominated framework in which the majority of costs are recouped through explicit capacity payments rather than through the energy-only market. Under such a system, capacity prices become the key adequacy indicator. Higher adequacy valuations, whether driven by stricter reliability standards or higher implicit VoLL, lead both to greater equilibrium volume of procured capacity and to a larger mark-up over underlying costs especially when few competitors are active. On the contrary, having more independent portfolios bidding in capacity auctions also through cross-border access lowers mark-ups and moves capacity closer to the competitive benchmark.

To this extent, the thesis finds that capacity mechanisms are systemically associated with lower average wholesale price dispersion while imposing substantial costs to consumers in certain Member States. In the current EU context, capacity mechanisms are fossil-fuel dominated, heterogeneous in cost and cross-border participation is limited due to national choices on adequacy parameters hindering the integration of the internal market. The analysis shown provides evidence that if the EU internal electricity market is to transit into a capacity-dominated market then three areas will need to be considerably further evolved:

i. harmonised and transparent adequacy governance;

ii. regional and competitive capacity mechanism design;

iii. alignment of capacity mechanisms design with flexibility and decarbonisation objectives.

From a policy perspective, three priorities emerge in the capacity mechanisms design. Adequacy governance has to integrate not only reliability metrics, but also cost-effectiveness, distributional considerations and grid enhancement needs, acknowledging that capacity mechanisms already constitute a significant burden on consumers with diverse impacts. Second, capacity mechanisms should be more regional, harmonised and competitive and cross-border participation should be a structural component as regional auctions would help mitigate market power and align adequacy decisions on a cross-regional basis in line with ERAA. Third, capacity mechanisms and eligibility criteria should be explicitly designed towards flexibility and decarbonisation, supporting low-carbon flexible resources while ensuring no lock-in of fossil technologies by steadily incorporating attributes such as duration, ramping capability and locational attributes into adequacy contribution and by updating CONE benchmarks.

It should be noted that the research has certain limitations that suggest important directions for further research. Statistically, due to the cross-sectional analysis, the identified associations between capacity mechanisms, price volatility and structural characteristics should be conceived as indicative correlations rather than causal estimates. Moreover, many features of real-world capacity auctions such as dynamic bidding, portfolio optimisation, technology-specific constraints and risk aversion are abstracted from the Cournot capacity model and thus should be considered as an analytical tool to demonstrate a future capacity-dominated market design rather than a quantitative forecasting tool. Future work could elaborate on the research results by using panel data of capacity mechanisms over time and calibrating more detailed oligopoly or agent-based models to specific regions.

References

Aurora Energy Research (2025). *Capacity remuneration mechanisms in Europe*. Available at: https://beyondfossilfuels.org/wp-content/uploads/2025/01/20250123_Aurora_BFF_CRM-Report_final.pdf (Accessed 23 December 2025).

European Commission (2025). *COMMUNICATION FROM THE COMMISSION Framework for State Aid measures to support the Clean Industrial Deal (Clean Industrial Deal State Aid Framework).* Official Journal of the European Union. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:C_202503602 (Accessed 23 December 2025).

European Commission (2025). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS 'European Grids Package'.* Official Journal of the European Union. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52025DC1005 (Accessed 28 December 2025)

ACER (2025) *Security of EU electricity supply.* Available at: ACER 2025 Security of EU electricity supply Monitoring Report (Accessed 23 December 2025).

European Commission (2025). REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL on the assessment of possibilities of streamlining and simplifying the process of applying a capacity mechanism under Chapter IV of Regulation (EU) 2019/943, in accordance with Article 69(3) of Regulation (EU) 2019/943. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52025DC0065 (Accessed 23 December 2025).

ENTSO-E (2025). *European Resource Adequacy Assessment Executive Report.* Available at: https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/sdc-documents/ERAA/ERAA_2024_ExecutiveReport_ACERApprovedAmendedVersion_August2025.pdf (Accessed 28 December 2025).

ENTSO-E (2025). *Proposed revision of the methodology for the European Resource Adequacy Assessment (ERAA)*. Available at: https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/sdc-documents/ERAA/ERAAMethodology_Redrafted_FinalProposal_Clean.pdf (Accessed 7 January 2026)

European Parliament (2025). *Fact sheets Internal Energy Market* Available at: https://www.europarl.europa.eu/ftu/pdf/en/FTU_2.1.9.pdf (Accessed 23 December 2025).

ENTSO-E (2025) *The role of Capacity Mechanisms to enable a secure and competitive energy transition*. ENTSO-E Policy Paper. Available at: https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/Publications/Position%20papers%20and%20reports/2025/entso-e_pp_capacity_mechanisms_250415.pdf (Accessed 23 December 2025).

World Bank (2025) *Metadata Glossary*. Available at: https://databank.worldbank.org/metadataglossary/doing-business/series/IC.ELC.SAID.XD.DB1619 (Accessed: 28 December 2025).

Lebeau, A., Petitet, M., Quemin, S. and Saguan, M. (2024). Long-term issues with the Energy-Only Market design in the context of deep decarbonization. *Energy economics*. Available at: https://www.sciencedirect.com/science/article/pii/S0140988324001269?via%3Dihub (Accessed 23 December 2025).

European Parliament and Council (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*. Official Journal of the European Union. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202401747 (Accessed 23 December 2025).

ACER (2024). *Security of EU electricity supply.* Available at: https://acer.europa.eu/sites/default/files/documents/Publications/Security_of_EU_electricity_supply_2024.pdf (Accessed 23 December 2025).

Menegatti, E., Meeus, L. (2024) An easy fix to streamline capacity markets. *European University Institute Florence School of Regulation*

Frontier economics (2023). *Energy market design with capacity mechanisms*. Available at: https://www.frontier-economics.com/media/shlb0hn0/energy-market-design-with-capacity-mechanisms.pdf (Accessed 23 December 2025).

Grubb, M. (2023) Disentangling the debate on electricity market (re)design and "split markets". *The Oxford Institute for Energy Studies*. Available at: https://cadmus.eui.eu/server/api/core/bitstreams/c0b5b557-2263-58a6-a7b2-29f643e58506/content (Accessed 23 December 2025).

Harvey, S.M., Hogan, W.W. (2023) Fundamentals define the constraints on electricity market design. *The Oxford Institute for Energy Studies*. Available at: https://cadmus.eui.eu/server/api/core/bitstreams/c0b5b557-2263-58a6-a7b2-29f643e58506/content (Accessed 23 December 2025).

Simoglou, C.K., Biskas, P.N. (2023) Capacity Mechanisms in Europe and the US: A Comparative Analysis and a Real-Life Application for Greece. *Energies* 16, 982. Available at: https://doi.org/10.3390/en16020982 (Accessed 23 December 2025).

European Commission (2022). COMMUNICATION FROM THE COMMISSION Guidelines on State aid for climate, environmental protection and energy 2022. Official Journal of the European Union. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022XC0218(03) (Accessed 23 December 2025).

ACER (2020). *Methodology for calculating the value of lost load, the cost of new entry and the reliability standard in accordance with Article 23(6) of Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity*. Available at: https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/sdc-documents/ERAA/ACER_Decision_23-2020_on_VOLL_CONE_RS_-_Annex_I.pdf (Accessed 23 December 2025).

ACER (2020). *Methodology for the European resource adequacy assessment in accordance with Article 23 of Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity*. Available at: https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/sdc-documents/ERAA/ACER_Decision_24-2020_on_ERAA_-_Annex_I_1.pdf (Accessed 23 December 2025).

ACER (2020). *Technical specifications for cross-border participation in capacity mechanisms in accordance with Article 26(11) of Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity*. Available at: https://www.acer.europa.eu/sites/default/files/documents/Individual%20Decisions_annex/ACER%20Decision%2036-2020%20on%20XBP%20CM%20-%20Annex%20I%20-%20technical%20specifications_0.pdf (Accessed 23 December 2025).

European Parliament and Council (2019). *REGULATION (EU) 2019/943 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019 on the internal market for electricity*. Official Journal of the European Union. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0943 (Accessed 23 December 2025).

European Parliament and Council (2019). *REGULATION (EU) 2019/943 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019 on the internal market for electricity*. Official Journal of the European Union. Available at: 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 (Accessed 23 December 2025).

Newbery, D. (2015) Missing Money and Missing Markets: Reliability, Capacity Auctions and Interconnectors. *Energy Policy Research Group*

Joskow, P. L. (2008) Capacity payments in imperfect electricity markets: Need and design. *Utilities Policy,* 16(3), pp. 159–170

Cramton, P., Stoft, S. (2006) The convergence of market designs for adequate generating capacity. *Center for Energy and Environmental Policy Research*

Motta, M. (2004) *Competition Policy: Theory and Practice*. Florence: European University Institute.

Appendices

Appendix A: EU 27 data

Source: ACER SoS Monitoring report 2024			Source: Electricity country sheets Monitoring data 2024						
Member State	**Country**	**Capacity mechanism status**	**Hours with prices <5 €/MWh (LP5)**	**Hours with prices >150 €/MWh (HP150)**	**Days with price swings > 50€**	**Spread**	**RES generation**	**HHI retail**	**HHI non-retail**
AT	Austria	No capacity mechanism	6,2	4,2	306	97,42	73%	6.590	1.330
BE	Belgium	Market-wide - central buyer	8,3	2,0	302	92,38	34%	2.680	2.540
BG	Bulgaria	No capacity mechanism	3,8	12,5	345	184,72	31%	3.500	
CZ	Czechia	No capacity mechanism	6,0	6,1	320	113,75	18%	2.870	1.100
DE	Germany	Strategic reserves	8,5	4,1	318	112,08	57%		
DK	Denmark	No capacity mechanism	8,5	3,8	303	103,03	89%	1.140	1.250
EE	Estonia	No capacity mechanism	8,1	11,2	339	115,36	63%	4.610	2.170
ES	Spain	No capacity mechanism	18,7	2,0	270	71,42	56%	2.360	1.230
FI	Finland	Strategic reserves	24,8	4,3	185	81,91	56%	1.010	940
FR	France	Market-wide - decentralised obligation	11,5	1,1	283	77,05	27%	4.670	2.500
GR	Greece	No capacity mechanism	3,0	10,7	341	162,86	51%	5.160	2.870
HR	Croatia	No capacity mechanism	4,7	10,2	327	148,5	74%	8.170	4.750
HU	Hungary	No capacity mechanism	5,4	12,3	333	183,75	31%	10.000	1.740

IE	Ireland	Market-wide - central buyer	1,5	12,4	323	99,78	46%	2.790	2.390
IS	Iceland	No capacity mechanism	-	-					
IT	Italy	Market-wide - central buyer	0,8	9,1	312	80,41	49%	2.460	770
LT	Lithuania	No capacity mechanism	7,8	11,2	338	151,38	72%	3.630	2.590
LU	Luxembourg	No capacity mechanism	8,5	4,1	318	112,08	50%	8.440	5.790
LV	Latvia	No capacity mechanism	7,7	11,3	338	151,6	72%		2.420
NL	Netherlands	No capacity mechanism	8,8	3,3	316	113,75	51%	1.750	1.500
NO	Norway	No capacity mechanism	10,3	0,5	57	31,12	99%	850	910
PL	Poland	Market-wide - central buyer	4,0	8,1	297	121,25	31%	2.410	1.350
PT	Portugal	No capacity mechanism	17,9	2,0	268	69,76	87%	4.090	1.650
RO	Romania	No capacity mechanism	4,0	12,9	344	188,81	50%	2.430	633
SE	Sweden	Strategic reserves	24,3	1,2	109	46,49	70%	870	870
SI	Slovenia	No capacity mechanism	4,9	8,4	323	138,34	42%	1.920	1.290
SK	Slovakia	No capacity mechanism	5,9	10,5	323	140,86	25%		

Source: ACER SoS Monitoring report 2025										
Member State	**Capacity revenue, EUR/MW for delivery year 2024**	**2024 costs to finance capacity mechanism (million euros)**	**Market-wide capacity auction clearing prices, delivery year 2025**	**MEC TSO, MW for delivery year 2026**	**MEC RCC, MW for delivery year 2026**	**procured, MW for delivery year 2026**	**TSO_RCC_gap**	**Use_ratio**	**Flexibility measures**	**Other measures**
AT									yes	backup reserve capacity
BE			15.695	1.260	2.210	1.260	-43%	100%		
BG									yes	
CZ										
DE		81,385							yes	backup reserve capacity
DK										
EE										temporary emergency restoration
ES									yes	
FI		-								
FR	28.151,49087	2.669,928	102.002	10.200	4.812	9.040	112%	89%	yes	interruptibility scheme
GR									yes	
HR									yes	
HU									yes	

IE		465,900	147.580							measure to shave the peak, temporary emergency restoration
IS										
IT	39.206,70245	1.797,000	45.000	4.365	0	4.365		100%	yes	interruptibility scheme
LT									yes	
LU										
LV										
NL										backup reserve capacity, temporary emergency restoration
NO										system protection schemes
PL	64.134,80248	1.412,457	196.408	1.527	453	1.539	237%	101%	yes	backup reserve capacity, interruptibility scheme
PT									yes	Non-standard ancillary servises
RO									yes	retention of existing generation

SE		7,300								
SI										
SK									yes	

Appendix A: EU 27 data (cont)

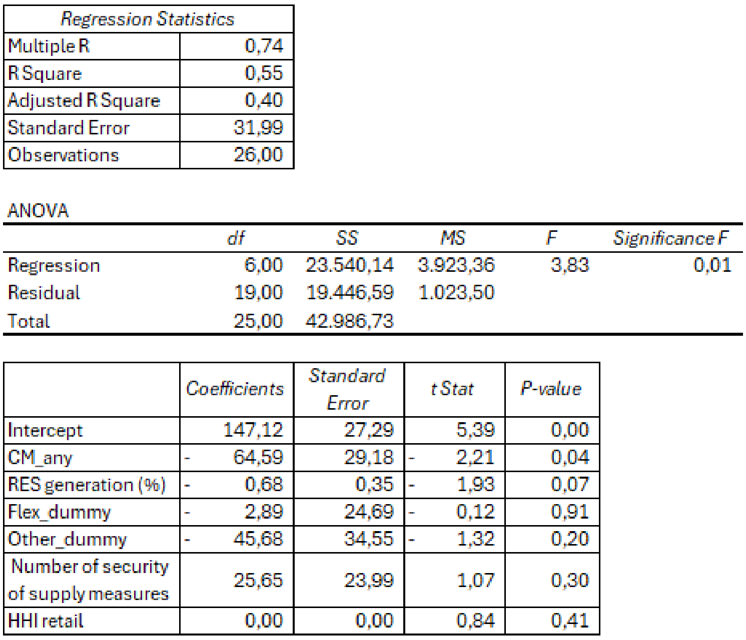
Source: ACER SoS Monitoring report 2025							Source: ACER SoS Monitoring report 2024	Source: Aurora		Source: Worldbank
Member State	**Number of security of supply measures**	**Single VOLL EUR/MWh**	**CONE fixed technology**	**CONE fixed EUR/MW**	**Reliability Standard h/year**	**System average interruption duration index (SAIDI) 2023**	**NRAA**	**Share_thermal (%)**	**Share_RES _flex (%)**	**Population**
AT	2					1,31	no			9.178.482
BE	1	12.832	demand response	30.000	3,00	0,67	yes	73	27	11.876.844
BG	1						yes			6.444.366
CZ	0	16.003	open cycle gas turbine	105.800	6,70	0,40	yes			10.882.164
DE	3	12.240	demand response/open cycle gas turbine	2.072 & 57.067/23.377	2,77	0,21	yes			83.510.950
DK	0	23.570		35.143		0,50	yes			5.976.992

EE	1	9.206	open cycle gas turbine	72.859	8,00	6,99	yes			1.371.986
ES	1	22.879	renewal & prolongation	34.400	1,50		yes			48.807.137
FI	1	8.000	renewal & prolongation	17.000	2,10	0,88	yes			5.637.214
FR	3	33.000	demand response	60.000	2,00	2,18	yes	63	27	68.516.699
GR	1	6.838	demand response	18.735	3,00	2,24	no			10.388.805
HR	1					6,58	no			3.866.300
HU	1					1,80	no			9.562.314
IE	3	17.909	open cycle gas turbine	115.990,00	3,00	1,76	yes	77	18	5.380.257
IS	0						no			404.610
IT	3	20.000	open cycle gas turbine	53.000	3,00	1,65	yes	84	12	58.986.023
LT	1						no			2.888.055
LU	0	12.240	demand response/open cycle gas turbine	33.905	2,77	0,22	yes			677.717
LV	0						yes			1.862.441
NL	2	68.887			4,00	0,36	yes			17.994.237

NO	1					2,10	no			5.572.272
PL	4	17.173	demand response/open cycle gas turbine	30.183/119.256	3,00	3,46	no	66	32	36.554.707
PT	2				5,00	2,85	yes			10.701.636
RO	2					1,73	no			19.069.340
SE	1	7.065	demand response	10.068	1,00	1,05	yes			10.569.709
SI	0	17.233	demand response	21.753		5,59	yes			2.126.324
SK	1						yes			

Appendix B: Regression results and correlation matrix

$$\text{Spread}_i = \alpha + \beta_1\text{CM\_any}_i + \beta_2\text{RES\_generation}_i + \beta_3\text{Flex\_dummy}_i + \beta_4\text{Other\_dummy}_i + \beta_5\text{Number of SoS\_measures}_i + \beta_6\text{HHI retail}_i + u_i \quad (1)$$



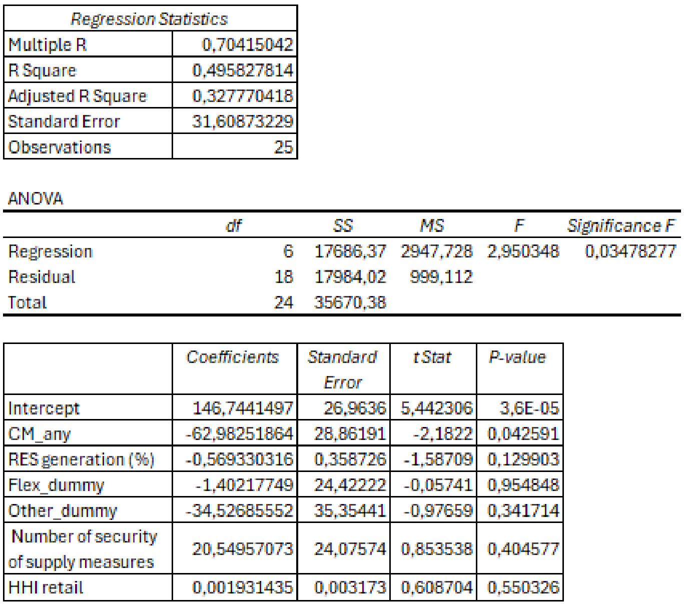
Regression Statistics	
Multiple R	0,74
R Square	0,55
Adjusted R Square	0,40
Standard Error	31,99
Observations	26,00

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6,00	23.540,14	3.923,36	3,83	0,01
Residual	19,00	19.446,59	1.023,50		
Total	25,00	42.986,73			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	147,12	27,29	5,39	0,00
CM_any	- 64,59	29,18	- 2,21	0,04
RES generation (%)	- 0,68	0,35	- 1,93	0,07
Flex_dummy	- 2,89	24,69	- 0,12	0,91
Other_dummy	- 45,68	34,55	- 1,32	0,20
Number of security of supply measures	25,65	23,99	1,07	0,30
HHI retail	0,00	0,00	0,84	0,41

Robustness results after excluding Norway:



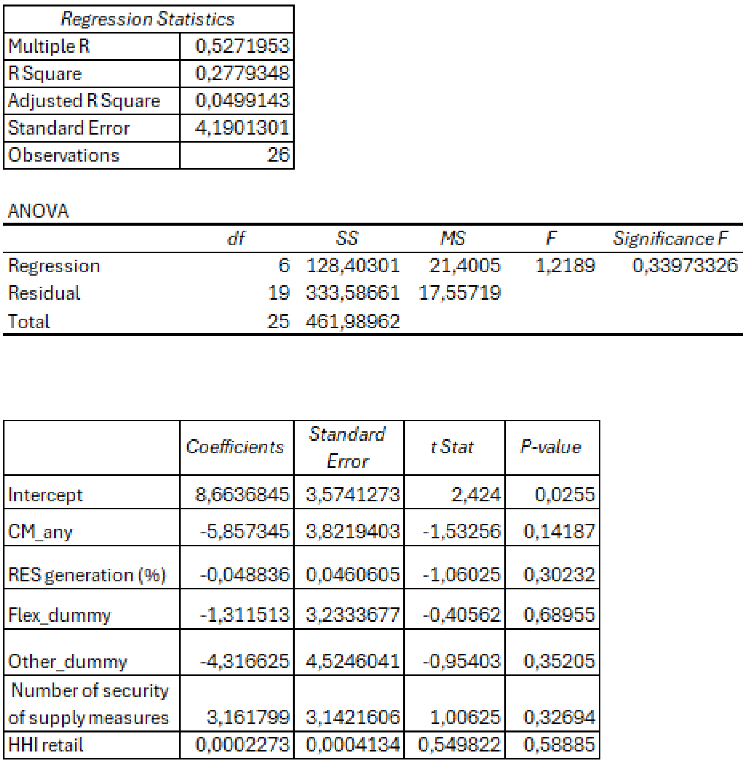
Regression Statistics	
Multiple R	0,70415042
R Square	0,495827814
Adjusted R Square	0,327770418
Standard Error	31,60873229
Observations	25

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	17686,37	2947,728	2,950348	0,03478277
Residual	18	17984,02	999,112		
Total	24	35670,38			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	146,7441497	26,9636	5,442306	3,6E-05
CM_any	-62,98251864	28,86191	-2,1822	0,042591
RES generation (%)	-0,569330316	0,358726	-1,58709	0,129903
Flex_dummy	-1,40217749	24,42222	-0,05741	0,954848
Other_dummy	-34,52685552	35,35441	-0,97659	0,341714
Number of security of supply measures	20,54957073	24,07574	0,853538	0,404577
HHI retail	0,001931435	0,003173	0,608704	0,550326

$$HP150_i = \alpha + \beta_1 CM\_any_i + \beta_2 RES\_generation_i + \beta_3 Flex\_dummy_i + \beta_4 Other\_dummy_i + \beta_5 Number\ of\ SoS\_measures_i + \beta_6 HHI\ retail_i + u_i \tag{2}$$



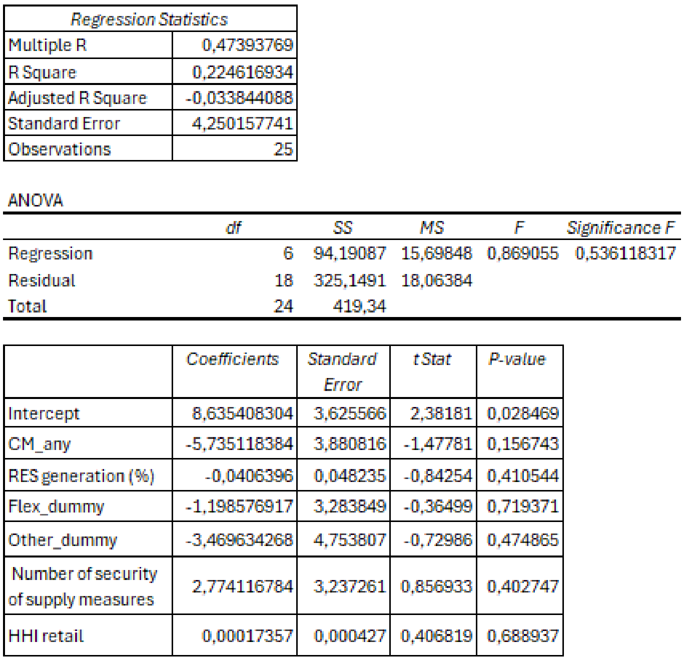
Regression Statistics	
Multiple R	0,5271953
R Square	0,2779348
Adjusted R Square	0,0499143
Standard Error	4,1901301
Observations	26

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	128,40301	21,4005	1,2189	0,33973326
Residual	19	333,58661	17,55719		
Total	25	461,98962			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	8,6636845	3,5741273	2,424	0,0255
CM_any	-5,857345	3,8219403	-1,53256	0,14187
RES generation (%)	-0,048836	0,0460605	-1,06025	0,30232
Flex_dummy	-1,311513	3,2333677	-0,40562	0,68955
Other_dummy	-4,316625	4,5246041	-0,95403	0,35205
Number of security of supply measures	3,161799	3,1421606	1,00625	0,32694
HHI retail	0,0002273	0,0004134	0,549822	0,58885

Robustness results after excluding Norway:



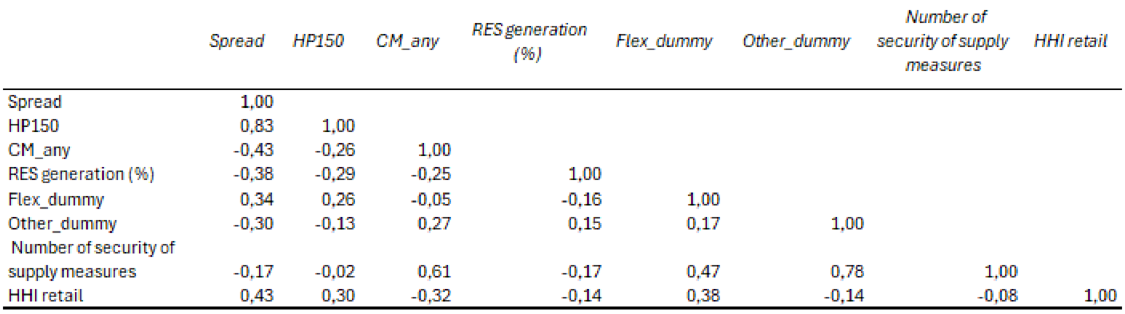
Regression Statistics	
Multiple R	0,47393769
R Square	0,224616934
Adjusted R Square	-0,033844088
Standard Error	4,250157741
Observations	25

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	94,19087	15,69848	0,869055	0,536118317
Residual	18	325,1491	18,06384		
Total	24	419,34			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	8,635408304	3,625566	2,38181	0,028469
CM_any	-5,735118384	3,880816	-1,47781	0,156743
RES generation (%)	-0,0406396	0,048235	-0,84254	0,410544
Flex_dummy	-1,198576917	3,283849	-0,36499	0,719371
Other_dummy	-3,469634268	4,753807	-0,72986	0,474865
Number of security of supply measures	2,774116784	3,237261	0,856933	0,402747
HHI retail	0,00017357	0,000427	0,406819	0,688937

Correlation matrix



	Spread	*HP150*	*CM_any*	*RES generation (%)*	*Flex_dummy*	*Other_dummy*	*Number of security of supply measures*	*HHI retail*
Spread	1,00							
HP150	0,83	1,00						
CM_any	-0,43	-0,26	1,00					
RES generation (%)	-0,38	-0,29	-0,25	1,00				
Flex_dummy	0,34	0,26	-0,05	-0,16	1,00			
Other_dummy	-0,30	-0,13	0,27	0,15	0,17	1,00		
Number of security of supply measures	-0,17	-0,02	0,61	-0,17	0,47	0,78	1,00	
HHI retail	0,43	0,30	-0,32	-0,14	0,38	-0,14	-0,08	1,00

Appendix C: Cournot Capacity Model

In this appendix Cournot equilibrium used in Section 4.4 is derived. The analysis follows the standard linear Cournot setup as Motta (2004) presented. However, the analysis interprets firms quantities as capacity.

There are n≥2 symmetric firms. Firm i chooses capacity ki≥0. Total capacity is:

$$K = \sum_{i=1}^{n} \mathrm{ki} \tag{3}$$

The inverse demand for capacity is linear:

$$p^{c}(K) = \alpha - \beta K \ , \ \alpha > 0 \ , \ \beta > 0 \tag{4}$$

Each firm has a constant annual capacity cost c>0 per MW. To this extent, the profit of firm i is:

$$\pi_i = (p^{c}(K) - c)\, k_i = (\alpha - \beta K - c)\, k_i \tag{5}$$

It is noted that firms choose k_i simultaneously, taking rivals choices as given.

Let

$$K_{-i} = \sum_{j \neq i} \mathrm{kj} \tag{14}$$

Then

$$K = k_i + K_{-i} \tag{15}$$

$$\pi_i\,(k_i, K_{-i}) = (\alpha - \beta\,(k_i + K_{-i}) - c)\, k_i \tag{16}$$

The first-order condition for an interior optimum is:

$$\frac{\partial \pi_i}{\partial k_i} = (\alpha - \beta(k_i + K_{-i}) - c) + ki\,(-\beta) = a - c - \beta K_{-i} - 2\beta k_i = 0 \tag{17}$$

Solving for ki gives the best-response function:

$$k_i = \frac{a - c - \beta K_{-i}}{2\beta} \tag{18}$$

This refers to the reaction functions in Motta (2004) after the demand is normalised and k_i is interpreted as output.

In a symmetric Nash Cournot equilibrium all firms choose the same capacity level k_i=k for all i.

Then

$$K=nk \tag{19}$$

$$K_{-i}=(n-1)k. \tag{20}$$

Substituting into the best-response condition:

$$k = \frac{a - c - \beta(n-1)k}{2\beta} \tag{21}$$

Multiplying both sides by 2β and rearranging:

$$2\beta k = a - c - \beta(n-1)k => \beta(n+1)k = \alpha - c \tag{22}$$

Hence the symmetric equilibrium capacity per firm is:

$$k^* = \frac{a - c}{\beta(n+1)} \tag{23}$$

and total capacity is:

$$K^* = nk^* = \frac{n(a-c)}{\beta(n+1)} \tag{24}$$

The equilibrium capacity price is obtained from the inverse demand:

$$p^{C*} = a - \beta K^* = \alpha - \beta\frac{n(a-c)}{\beta(n+1)} = \frac{a + nc}{n+1} \tag{25}$$

If Motta's normalisation is followed and set α=1, β=1 and interpret K as output, these expressions lead to the Cournot outcome which is exactly Motta's p*(Motta, 2004).

$$q^* = \frac{1-c}{1+n} \tag{26}$$

$$p^* = \frac{1+nc}{n+1} = \frac{c\,(n+1) + 1 - c}{n+1} = \frac{c(n+1)}{n+1} + \frac{1-c}{n+1} = c + \frac{1-c}{n+1} \tag{27}$$

Under perfect competition capacity is chosen such that price equals cost:

$$P^C(K^{comp}) = c => a - \beta K^{comp} = c => K^{comp} = \frac{\alpha - c}{\beta} \tag{28}$$

Comparing the Cournot and competitive outcomes:

- Capacity level

$$\frac{K^*}{K^{comp}} = \frac{n}{n+1} \tag{29}$$

so Cournot competition results in under procurement of capacity relative to the competitive benchmark. The ratio approaches 1 as n increases.

- Capacity price and mark-up

$$p^{C*} - c = \frac{\alpha + nc}{n+1} - c = \frac{\alpha - c}{n+1} \tag{30}$$