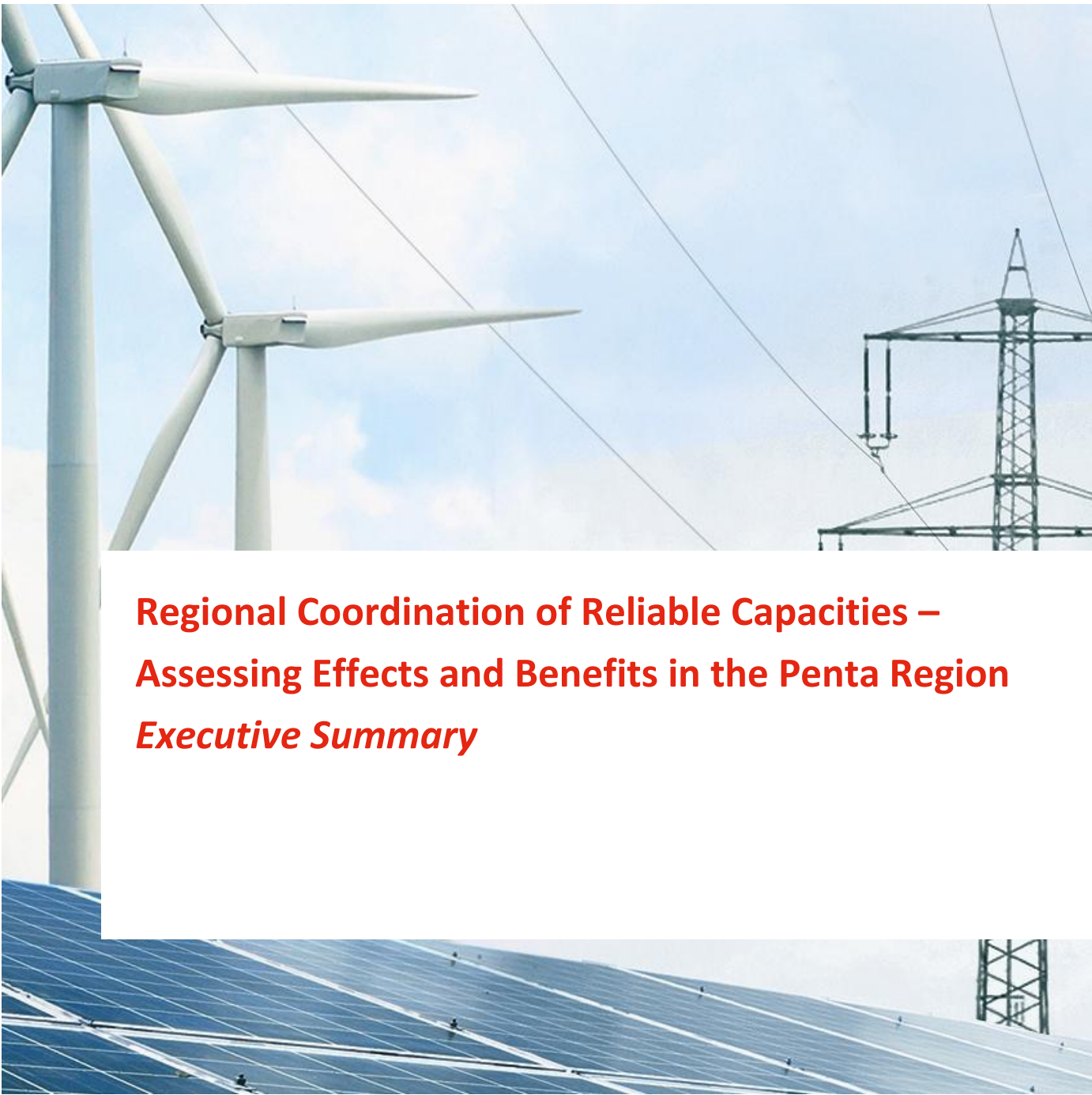


The background of the top half of the page features a photograph of renewable energy infrastructure. On the left, the white blades and tower of a wind turbine are visible against a blue sky with light clouds. On the right, a high-voltage electricity pylon stands. The bottom half of the page shows a close-up of a solar panel array, with the blue glass and silver metal frames of the panels clearly visible.

Regional Coordination of Reliable Capacities – Assessing Effects and Benefits in the Penta Region *Executive Summary*

Final Report

Commissioned by the

Federal Ministry for Economic Affairs and Energy (BMWE)
with expert support from the Pentilateral Energy Forum

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Executive Summary

The study analyses the possible added value of cooperation in driving capacity expansion in the region of the Pentalateral Energy Forum (“Penta region”). The analysis contributes to a better understanding of how coordinated approaches to resource adequacy and cross-border resource sharing can enhance system resilience, particularly under stressed and crisis conditions. Reliable capacity in this context may be provided through different adequacy instruments, including capacity mechanisms or strategic reserves. The analysis shows that a demand-oriented and coordinated expansion of capacities in the Penta region can achieve a comparable level of security of supply with less installed capacity for those scenario variations compared to the reference scenario. These benefits of coordination are observed not only under normal conditions but also in crisis scenarios. The modelling approach is built on a European reference scenario that ensures resource adequacy, complemented by several stylized variations that deliberately tighten adequacy conditions (e.g., through reductions in available capacity).

Over the past decades, short-term electricity markets in Europe have become increasingly integrated. However, decisions affecting resource adequacy and the expansion of generation capacities remain largely national topics and are hence shaped by individual policy objectives. This misalignment between market integration and national resource adequacy assessments can lead to inefficiencies. Some countries may pursue strategies aimed at a high degree of national self-sufficiency, resulting in structural overcapacity at the system level when followed by all countries. At the same time, countries may rely excessively on free riding by imports, leading to structural undercapacity and increased vulnerability to supply shortages, especially during periods of stress or crisis when reliable capacity instruments beyond market-based outcomes may play an important role. As a result, the overall system may face both redundant investments or insufficient firm capacity in critical situations. A more efficient approach would consider the physical interconnectedness of the European power system and the potential benefits of coordinated planning. Leveraging cross-border synergies can reduce total capacity requirements and costs while maintaining, or even improving, security of supply.

This study was commissioned and funded by the German Federal Ministry for Economic Affairs and Energy (BMWE) and was developed in close cooperation with the Pentalateral Energy Forum. It follows the *Penta statement on the need to ensure a resilient electricity system for future electricity crises*, in which the Penta region agreed to assess the economic costs and benefits of reliable capacity provision (e.g., via capacity mechanisms or reserves) and cross-border cooperation in electricity crisis situations. The study design was developed in collaboration with experts from the Penta region.¹

This study investigates whether a sweet spot exists between the two extremes described above, i.e., a level of coordinated planning that reflects realistic expectations of cross-border support. It should be demonstrated whether it would be theoretically possible to achieve a high level of resource adequacy through cooperation and joint coordination, while at the same time avoiding the redundant capacities and investments.

Study design

¹ The contents of the study reflect solely the views of the authors and do not necessarily represent those of the BMWE or the Pentalateral Energy Forum. The results were extensively discussed with experts from the Pentalateral Energy Forum.

The analysis focuses on the region covered by the Pentilateral Energy Forum (AT, BE, CH, DE, FR, LU, NL) and is based on a 2040 electricity system aligned with assumptions taken based on TYNDP 2024. Whilst such long-term planning scenarios have the advantage of providing a commonly agreed and consistent input dataset, they ensure resource adequacy by design. Hence, to make the effects of alternative capacity expansion approaches observable, this study applies stylized capacity reductions as variation to this scenario, deliberately inducing scarcity situations characterized by Energy Not Served (ENS) and Loss of Load Expectation (LoLE) within the Penta region and hence providing an exemplary foundation to assess capacity needs.

Based on this, the capacity requirements aiming to reach a level of ENS of 0 MWh/a, are determined under three distinct cooperation assumptions, allowing for a systematic assessment of how different degrees of cross-border coordination affect overall capacity needs, free-riding incentives, and security of supply.

1. In the “Import Dependency” approach, each country minimizes its domestic capacity investments assuming sufficient support from neighboring systems, only limited by available transmission capacities, to be available during periods of scarcity. As a result, countries only build the capacity that is strictly necessary to cover demand while implicitly relying on imports. Consequently, this approach leads to minimal domestic capacity levels.
2. In the “Autarky Plus” approach, each country plans its capacity expansion under the assumption that it must be able to support all shortages in neighboring systems up to the level of transmission capacities available. This effectively eliminates all adequacy risks from a national perspective, as sufficient capacity is ensured even under stressed system conditions and widespread scarcity events. However, if all countries follow this approach simultaneously, it leads to systematic redundant capacities, as multiple countries build capacity to cover the same potential shortage events.
3. The “Coordination” approach represents an intermediate. It assumes a coordinated, system-wide optimization of available capacities, in which countries support each other based on solidarity principles, while respecting their own adequacy constraints. In this framework, cross-border exchanges are determined endogenously: countries provide support to neighboring countries whenever they have available capacity, but only to the extent that this does not create or exacerbate scarcity within their own system (i.e. no additional loss of load is induced domestically). In case of simultaneous scarcity in two or more neighboring countries, a country portions its support equally. In other words, shortages are not exported, and mutual support is limited by the physical and adequacy constraints of each system.

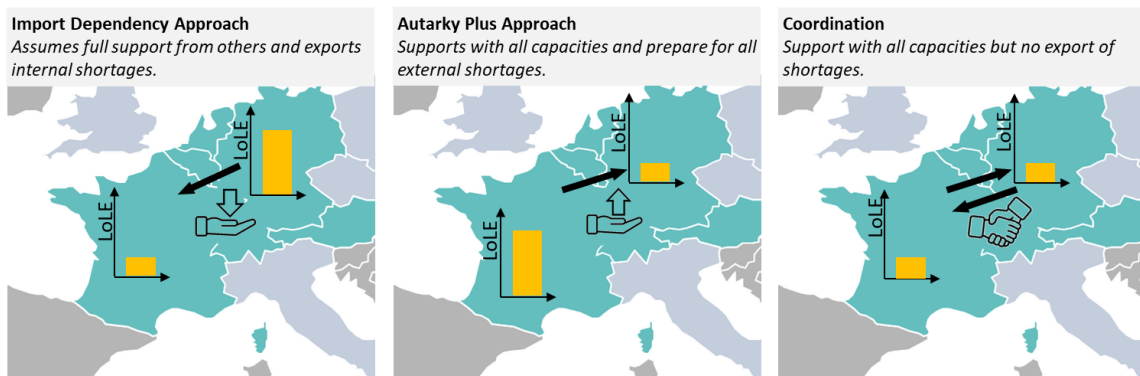


Figure 1 *Illustration of the three cooperation cases for France (FR) as the country under consideration. In the first case, shortages are exported; in the second, shortages are imported. In the third case, no shortage is exchanged.*

Moreover, the study systematically evaluates the different scenario variations across both dimensions of cooperation and system conditions. Each scenario variation is analyzed under the three approaches described above and for the two system states

- normal conditions, and
- a crisis setting.

The crisis setting is represented by a uniform and significant reduction in import capacities from non-Penta countries into the Penta region, thereby limiting external support to the Penta region and increasing stress on the internal system.

Findings

The study shows that across all scenario variations, the assumption of the Import Dependency approach leads to the lowest capacity investments hence leading to the lowest level of resource adequacy for the Penta region. In contrast, assuming the Autarky Plus approach results in substantially higher capacity expansion. The Coordination approach consistently lies between these extremes, showing a high level of resource adequacy with a reduced amount of capacity investments. Whilst the absolute values of capacity needs provide a wide range across scenario variations, as shown in Figure 2, the relative order of the cooperation cases remains robust across all scenario variations investigated. National individual countries' assumptions on cooperation and external support during scarcity situations significantly influence overall system capacity.

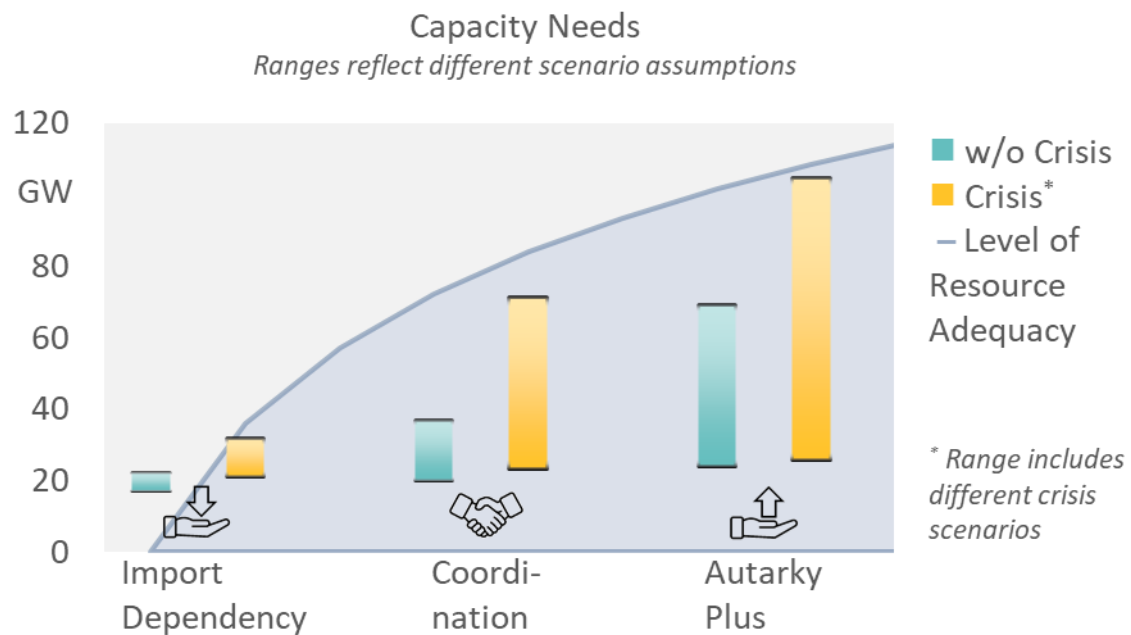


Figure 2 *Ranges of Capacity Needs across scenario variations and per cooperation assumption (left) without crisis and (right) including crisis scenarios*

Higher capacity does not translate proportionally into higher resource adequacy per se. The Coordination approach achieves resource adequacy comparable to the conservative Autarky Plus approach, with a LoLE close to zero across all scenarios. By contrast, the Import Dependency approach, while minimizing capacity needs, leaves small residual adequacy risks.

These trends are also observed in the crisis state, characterized by restricted exchange between the Penta and non-Penta regions. While the relative effects and patterns compared to the normal state remain largely consistent, significantly higher capacity requirements emerge under crisis conditions. For the set of investigated scenario variations and crisis assumption, capacities required to ensure adequacy in the crisis state are also sufficient under normal conditions. Consequently, and non-surprisingly, planning for crisis scenarios inherently provides robustness for non-crisis situations across the scenario variations under consideration. However, no conclusions can be drawn regarding the economic efficiency of such a crisis-oriented planning approach, as this requires assumptions about the probability and frequency of crisis events, which are beyond the scope of this study.

Conclusion

Coordination improves efficiency without compromising resource adequacy in the Penta region and can help avoid unnecessary capacity expansion. Overall, the analysis indicates that uncoordinated, conservative national capacity expansion strategies tend to create overcapacity without delivering significant additional reliability benefits at regional level. In contrast, overly optimistic assumptions about external support can undermine adequacy. Coordinated capacity expansion emerges as a robust and efficient approach in interconnected systems, achieving a high resource adequacy with lower overall capacity requirements. While the absolute figures depend on the underlying scenario assumptions, the structural conclusion is clear: The results highlight the potential value of regional coordination when designing adequacy instruments in interconnected electricity systems.

The results highlight that coordination is not only a key element of “normal” adequacy planning but becomes even more critical in the context of risk preparedness. Given the higher capacity needs in crisis scenarios, effective cross-border cooperation is particularly essential for developing credible and efficient risk preparedness strategies. This suggests a need to better align existing frameworks for adequacy and risk preparedness. In particular, it is recommended, when updating the requirements under the Risk Preparedness Regulation and while mandating EU Member States to prepare for electricity crisis situations, to consider how these requirements may align with the design and implementation of capacity remuneration mechanisms, where relevant. The results indicate that current arrangements, including existing provisions for cross-border participation in capacity mechanisms, may not be sufficient to fully capture the benefits of coordinated planning. Therefore, further work is needed to assess how coordination can be implemented more effectively in practice, for example through a stronger integration of regional perspectives in ERAA processes and national risk preparedness plans.