Study on Next Generation *Day-Ahead and Intraday* Market Coupling IT-Architecture

Capgemini invent

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Executive Summary

Europe's day-ahead (DA) and intraday (ID) wholesale power markets are approaching their technical limits. Separate architectures for DA and Intraday Auctions (IDAs, Euphemia) and ID (XBID) create duplication, diverging data models, and operational distress. The planned major expansion of the grid infrastructure will intensify the challenges: while it promises higher flexibility and security of supply, it also adds complexity and the need for significant IT and operational adjustments in short-term markets. In combination with growing trading volumes, accelerating renewable integration, and the shift toward real-time operations, incremental improvements will not be enough.

The solution is a **harmonized and modularized market** IT-Architecture that unifies DA and ID on a single technology stack while preserving each of their proven market logic.

1. **Shared core services:** Establish a unified data model, interface layer, identity management and observability framework.

2. **Modular integration:** Connect existing DA and ID modules via standardized interfaces.

3. **Unified infrastructure:** Consolidate transport, run-time, and monitoring on a secure private backbone.

Key benefits include

- **Consistency & lower cost:** A single data model and identity layer simplify integration and reduce lifecycle costs.
- **Operational coherence:** Aligned testing and release management ensure faster and more reliable deployments.
- **Resilience & security:** A high-availability backbone with automated failover enhances system robustness.
- **Regulatory transparency:** End-to-end data visibility provides oversight and builds trust.

This IT-Architecture ensures that Europe's DA and ID systems are future-proof, modular, secure, and able to handle the increasing complexity of the energy transition.

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01

Introduction: The Case for Transformation

Moving towards a more robust IT-Architecture

The increasing intricacy of the European energy market demands a more sophisticated approach to information technology architecture. As the continent's power landscape evolves, the ability to anticipate and manage rising complexities has become essential.

Main principles of European market coupling

Transmission System Operators (TSOs) and Nominated Electricity Market Operators (NEMOs) collaborate as equal partners in European electricity market coupling and are jointly responsible for the operation of European electricity market coupling. Recognizing the study from the European Commission on ID market design, TSOs and NEMOs are urged to follow the principle of balanced responsibilities[1]. Treating hardware and software assets including the market coupling algorithm, as common assets would strongly support this principle. A governance framework that ensures parity in ownership and decision-making rights can serve as a guiding model. This study describes a greenfield approach, so the set-up of a next generation IT-Architecture starts via a new tender for all hardware and software devices including the market coupling algorithm.

Objectives of this study

The primary focus of the study is on the core architectural elements of infrastructure, security, robustness, and testing. Other aspects are acknowledged, but they are not the main emphasis of the analysis. The objective is to move beyond incremental innovation and to develop a robust, cohesive system framework that can adapt to the evolving security requirements of TSOs and the broader market. The study further examines how next generation IT-Architecture must be designed to enable seamless integration, scalability, and reliability across the European energy landscape.

Scope and exclusions

The scope is deliberately defined to ensure clarity and precision. While the study addresses the needs and perspectives of both TSOs and other market stakeholders, it explicitly excludes organisational, legal, and governance topics, as well as wider market design discussions. Considerations for future market design are not forecasted in this study. However, it is acknowledged that both the overall complexity and the traded volumes are expected to increase. The study provides foundational insights and key pillars for future implementation in a rapidly evolving technological and regulatory environment.

Ultimately, this work serves as a conceptual guide, mapping out the possibilities for resilient, future-oriented IT-Architecture in Europe's physical spot markets and laying the groundwork for transformative change.

Towards a high-performance market coupling architecture

The creation of a coupled European electricity market stands as a monumental success. The Single Day-Ahead Coupling (SDAC) and Single Intraday Coupling (SIDC) frameworks now connect 32 TSOs and 17 NEMOs across 26 countries, fostering unprecedented levels of market efficiency, optimizing cross-border capacity, and enhancing security of supply[2]. This integration was achieved through a series of valuable but ultimately incremental solutions, building upon existing systems and processes to forge a pan-European marketplace.

While this approach has supported the market in the past, its fundamental limitations are now increasingly evident. The IT-Architecture that once enabled success is straining under rapidly changing operational needs, new regulatory requirements, and rising stakeholder expectations. Unsystematic innovations are no longer sufficient. The complex challenges of today's energy landscape demand a comprehensive architectural transformation, rather than further incremental fixes. This study outlines the key architectural elements required to enable such a technological transformation.

Exponential trading growth

Driven by the rapid expansion of renewables and the rise of automated trading, Europe's power markets are experiencing an exponential surge in transaction volumes, number of traders, data flows,

1. European Commission. (2019). The future electricity intraday market design. Publications Office of the European Union. https://data.europa.eu/doi /10.2833/004191
2. NEMO Committee. (2025). CACM Annual Report 2024: Single Day-Ahead and Intraday Coupling. https://www.nemo-committee.eu/assets/files/cacm-annual-report-2024.pdf

and operational complexity, reshaping the very foundations of market coupling and system design[2,3].

The sheer volume of transactions and data flowing through the market coupling systems is growing at a relentless pace. This growth is not linear but exponential, driven by powerful macroeconomic and technological trends. A stark indicator of this is the activity within the Cross-Border Intraday Market (XBID) system for continuous intraday trading, where the number of trades is growing significantly since its launch in 2018. This is not a temporary surge but a reflection of a new market reality. In line with the EU's "Fit for 55" targets, the combined output from photovoltaic, wind, and storage assets is projected to triple within the next decade (see Figure 1[4]).

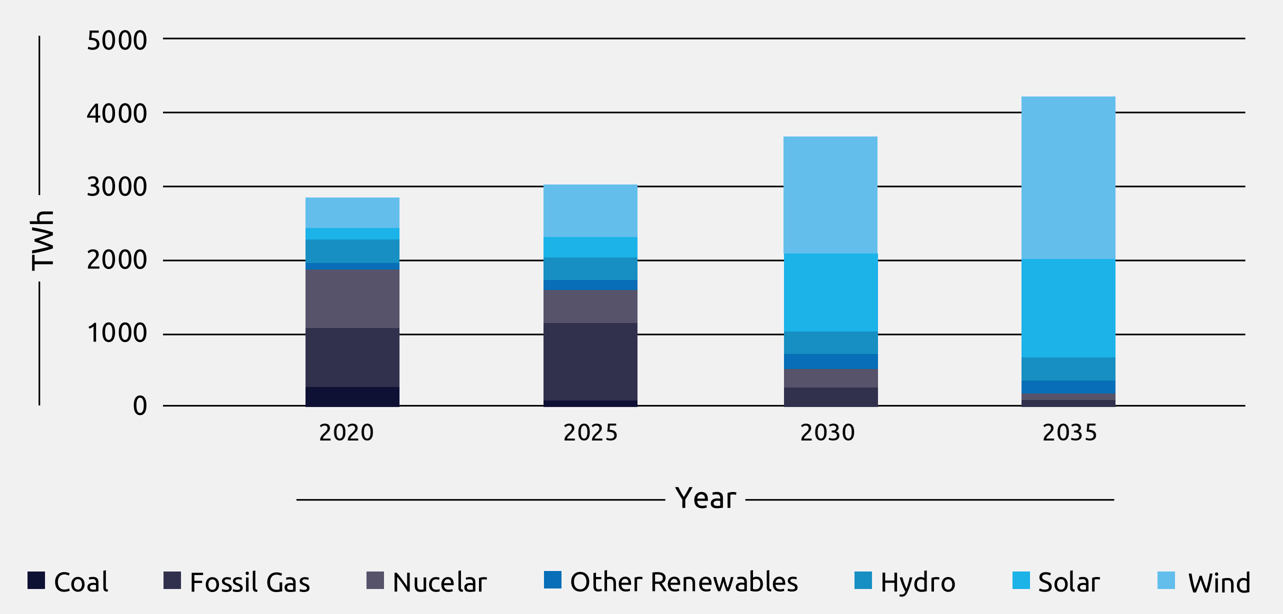


Figure 1: Forecasted increase of renewable generation capacity in Europe

As the proportion of variable renewables on the grid increases, the timeframe for market operations is contracting. Trading is moving ever closer to real-time to manage the inherent intermittency of wind and solar power. Renewable producers, facing the risk of imbalance penalties, increasingly adopt a multi-stage trading strategy: they sell conservative estimates in the day-ahead market and refine their positions in the intraday market as forecasts improve. This elevates the intraday market to a primary trading venue, demanding fast and flexible access. Furthermore, the reduction of the Intraday Cross-Zonal Gate Closure Time (ID CZ GCT) to just 30 minutes before delivery will concentrate even more EU-wide trading activity into the final minutes, increasing the volumes further[4].

Simultaneously, demand-side trends, including the rapid adoption of electric mobility and heating, alongside the energy appetite of data centres and artificial intelligence, are driving overall power consumption and trading activity higher. Whereas data centres servers cannot be simply turned off, data centres are increasingly capable of participating in Demand Side Response (DSR). A future-proof IT-Architecture must not only be able to handle the increased overall demand but must also be designed to facilitate and reward the participation of such large flexible resources. It needs to provide the real-time price signals and low-latency communication channels necessary to enable automated DSR at scale.

2. NEMO Committee. (2025). CACM Annual Report 2024: Single Day-Ahead and Intraday Coupling. https://www.nemo-committee.eu/assets/files/cacm-annual-report-2024.pdf
3. European Commission. (2019). Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity (PE/9/2019/rev/1). Official Journal of the European Union. http://data.europa.eu/eli/reg/2019/943/oj
4. Ember. (2022). New Generation: Building a clean European electricity system by 2035 [Report]. https://ember-energy.org/app/uploads/2022/06/Report-New-Generation-23.06.22.pdf

Increasing complexity in trading process

As Europe's power markets evolve towards finer granularity, faster cycles, and smarter automation, the trading process is undergoing a profound transformation, marked by exponential growth in data, decision speed, and structural sophistication.

The EU-wide shift to 15-minute market time units (MTUs) has already intensified message volumes and shortened decision cycles, placing pressure on system latency and throughput. The shift from 24 hourly periods to 96 quarter-hourly periods represents a quadrupling of the dimensionality, number of variables and constraints that the auction algorithm must solve. This trend is quantitatively illustrated for IDCT in Table 1[5], which highlights the growing strain on post-coupling processing times and system scalability.

Metric	Aug 2021	Mar 2025	Change	Trend
Order Execution (93rd %ile)	15ms	22ms	+47%	Slower system throughput
Order Execution (96.5th %ile)	20ms	35ms	+75%	Slower system throughput
Daily Orders	1.8M	23.3M	+1,165%	Growth in # of orders
Post - Coupling Generation	11.2s	52.0s	+365%	Slower system throughput
Trades per Hour	6,633	40,215	+506%	Growth in # of trades

Table 1: Key Platform Performance Metrics: August 2021 vs. March 2025

The continuous intraday market has fostered a new ecosystem of specialized traders who deploy highly automated, Artificial Intelligence (AI) driven strategies. These "AI systems" are autonomous bots capable of simulating strategies, learning from market outcomes, and adapting in real-time to a flood of signals, including weather forecasts and grid conditions. Such strategies depend on an ultra-low-latency, high-throughput IT infrastructure, as well as centralized load management.

In today's fast-paced market environment, even minor delays can lead to major disruptions, including market-wide shutdowns, algorithm-driven "flash crashes" with sharp and volatile price movements that risk grid stability, and increased pressure on clearing and settlement systems.

Increasing sophistication and growing topology

This complexity is also structural. The day-ahead markets evolved beyond simple hourly bids to accommodate the physical realities of power plants of different sizes and technologies. This led to the introduction of "smart" order types, such as all-or-nothing blocks, minimal thermal conditions, load gradients in Euphemia and limit orders, Iceberg, block orders for XBID. These add additional computational challenges to the algorithms. Power markets will continue to develop, and new players and technologies will join them. For Battery Energy Storage Systems (BESS) for instance, traditional order types are not enough and more "tailored", sophisticated products will be offered by NEMOs and need to be accommodated by the trading algorithms.

There is increasing complexity in the topology as well, driven by the growing number of bidding zones and the expansion of grid infrastructure. Each new addition increases the computational and communicational load, straining system performance and the core efficiency of market coupling. The risk profile of the system has fundamentally shifted. Performance bottlenecks are no longer merely a source of economic inefficiency.

In addition to these market-side factors, the strain on the current IT-Architecture will be further enhanced by the wider implementation of Flow-Based Market-Coupling (FB-MC) in both day-ahead and intraday markets, including Advanced Hybrid Coupling (AHC) between Flow-Based Capacity Calculation Regions (CCRs). Not only Euphemia, but XBID will need to deal with flow-based domains for the FB-IDCT (Flow-Based Intraday Continuous Trading), enabling a better alignment between the status of the grid and market needs.

Against this backdrop, the current market IT-Architecture is fragmented, a legacy of the historical establishment of day-ahead and intraday market coupling systems. It relies on a "dual stack" setup: one system built around the Euphemia algorithm for auctions, and another based on the XBID platform for continuous trading. Each stack is supported by its own separate IT infrastructure, leading to diverging data models, security systems and monitoring tools. This fragmentation creates operational complexity, the need for additional interface communication layers (e.g. the common interface point fur running the IDAs and increases lifecycle costs[6]. The fragmented communication infrastructure uses varied networks, communication and security protocols, not only increases costs for TSOs and NEMOs but also expands the cybersecurity attack surface and complicates coordinated incident responses.

The combination of the current monolithic IT-Architecture and the significantly increased requirements for market coupling IT systems, including resilience, cybersecurity (such as a European-hosted collaboration platform for AI applications), computational prowess, and implementation speed, highlight growing systemic pressure. The rising demands call for a fundamental transformation of the EU's market coupling IT-Architecture.

The next chapter presents eight building blocks that define the next generation IT-Architecture for auctions and continuous trading.

5. ENTSO-E. (2025). Single Intraday Coupling (SIDC). https://www.entsoe.eu/network_codes/cacm/implementation/sidc

6. European Commission. (2019). EC study on ID market design. MESC Stakeholder Committee. https://eepublicdownloads.entsoe.eu/clean-documents/Network%20codes%20documents/Implementation/stakeholder_committees/MESC/2019-09-17/190917_5.8_EC%20study%20on%20ID%20market%20design.pdf

02

Solution Horizon:

Key Building Blocks

The strategic vision for a future-proof market coupling IT-Architecture is realized through eight interconnected building blocks. They address the fundamental weaknesses of the current system including fragmentation, slow and risky change management, and reactive operations and monitoring. This is realized by introducing harmonization, scalability, and intelligence as core design principles.

Creating a single, coherent technology core to eliminate fragmentation and duplication

Block 1

Future power markets IT-Architecture is based on an integrated and harmonized single technology stack, ensuring consistent processes and seamless interoperability across the physical spot markets

Status Quo: The current IT-Architecture for market coupling is fragmented due to the separate historical development of day-ahead and intraday trading. This has led to a “dual-stack” setup where two parallel systems are in use: one based on the Euphemia algorithm for day-ahead and intraday auctions, and another utilizing the XBID platform for continuous SIDC trading.

Each of these market-clearing systems is supported by its own independent infrastructure, resulting in the duplication of components such as market interfaces, data models, identity and access management systems, and monitoring tools. This architectural duplication contributes to operational complexity, raises lifecycle costs, and makes it challenging for regulators and system operators to achieve a consolidated, end-to-end view of market activities.

Future Vision: The proposed solution integrates existing technology stacks while maintaining a clear separation between the core Market-Coupling-Algorithm, which remain unchanged, and the surrounding common services. The objective is to consolidate these support systems into a single, unified stack without altering distinct market logics. This redesign eliminates duplication by establishing a coherent technology core complemented by a shared layer of foundational services.

- **A standardized market data repository** will establish a common language, for example using Common-Information-Model, and a single source of truth for all market coupling interactions. This model acts as the platform’s central nervous system, serving as a standardized repository that ingests, validates, stores, and delivers data. It will manage a wide range of information, including submitted bids and offers, TSO grid models, calculated cross-zonal capacities, market results, settlement data, and historical archives.

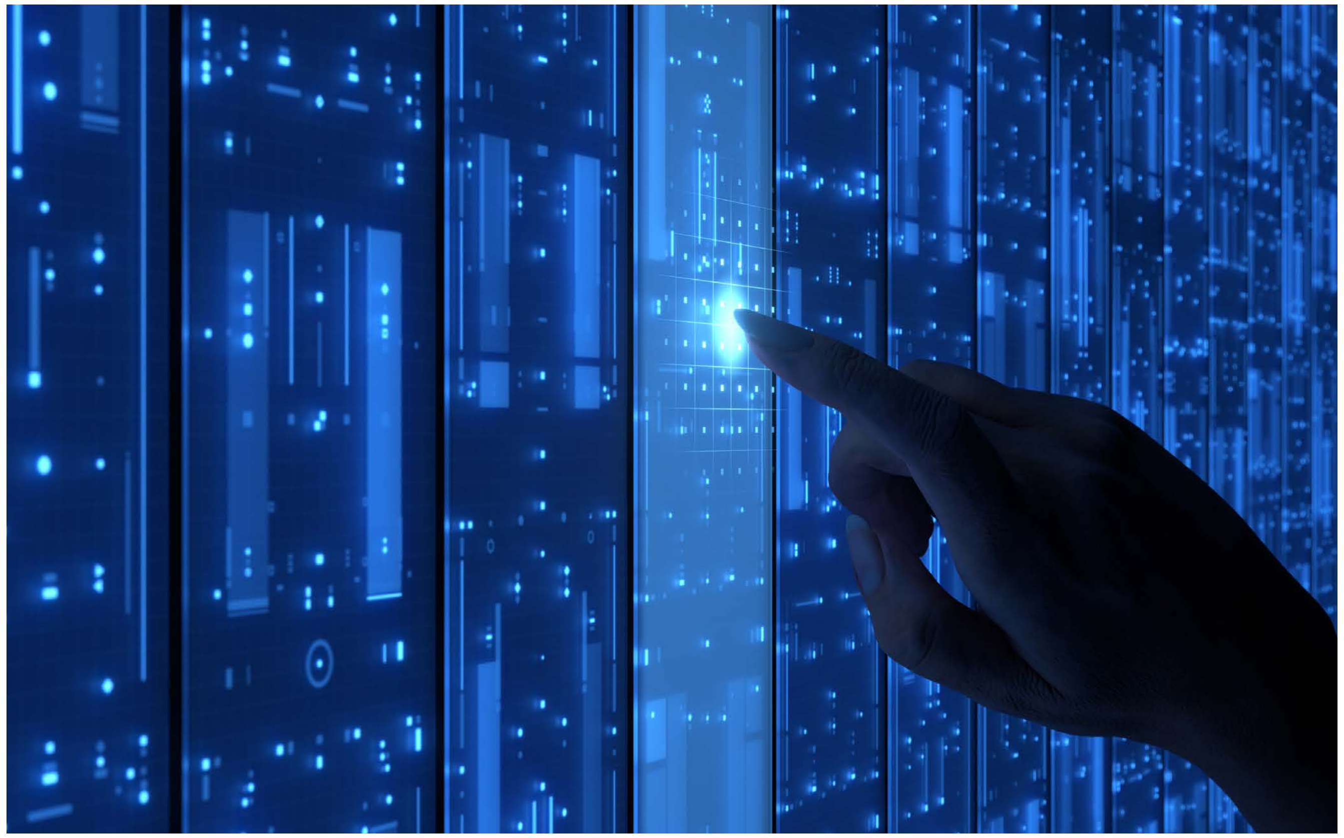
- **A common Application Programming Interface (API) layer** connects all core market modules within the platform's architecture, enabling seamless interaction through a standardized data model and supporting both auction and continuous trading algorithms. This unified API backbone ensures interoperability, simplifies integration, and reduces complexity across the system. Interfaces will connect Local Trading Solutions (LTS), TSO central systems such as Pan-European Verification Function (PEVF), and other local infrastructures, creating a fully interoperable ecosystem.

- **Unified identity and access management** to enhance security and streamline user onboarding.

- **A single observability system** to provide a holistic, end-to-end view of system health and market activity.

This architectural unification directly addresses the critical data fragmentation and operational inefficiencies inherent in the current dual-stack system. By introducing a common layer of foundational services and a unified API backbone, while preserving the proven core market-clearing algorithms, the common platform will ensure interoperability and simplify integration. This approach prepares the system for future market complexities, such as integrating Flow-Based Market Coupling into continuous trading, while improving data consistency and maintainability. A crucial step is also to consolidate the separate operational databases into a unified data architecture, breaking down data silos (single source of truth) and enabling comprehensive, cross-market analytics.

Ultimately, this foundational alignment establishes a more resilient, scalable, and transparent technology core, ensuring the long-term stability and integrity of the European physical spot markets.



Block 2

A modular algorithm platform with a common data repository for auctions and continuous trading

Status Quo: Europe's power market architecture is built on monolithic, proprietary systems.This separation between continuous intraday trading (via XBID) and auction-based day-ahead (via Euphemia) reflects historical design choices increasingly misaligned with evolving operational needs. Increasing renewable integration and finer market time units expose inefficiencies and performance limits of maintaining siloed platforms. This architectural fragmentation adds unnecessary complexity and risk for TSOs who must operate across both paradigms.

Market and system operators are prevented from leveraging a competitive market of specialized solution providers to procure "best-in-class" components, such as more efficient computational solvers or advanced risk management modules. The inherent complexity of maintaining and upgrading these large, separate and monolithic systems also leads to critical operational bottlenecks and limited testing capacities.

Future Vision: The future solution is a centrally hosted, modular, and vendor-agnostic platform. Existing monolithic systems will be "hollowed out" by identifying common, non-core functionalities and rebuilding them as shared, independent modules or microservices on the common platform, extracting and modularizing high-value, duplicated business capabilities from Euphemia and XBID. Key candidates for initial extraction include non-core-matching functions such as:

- **Capacity Management:** Standardized interfaces for TSOs to manage cross-zonal capacities.

- **User and Participant Management:** A unified service for authentication and authorization.

- **Trade Reporting and Post-Trade Processing:** A common module for providing data to clearing and settlement.

- **Market Data Publication:** A single API for disseminating public market data.

This approach keeps high-risk core matching engines separate and untouched during the initial phase, while the surrounding ecosystem of supporting services converges onto a single, modern, and efficient platform. While bringing modules under one roof may introduce a single point of failure, this risk is mitigated by the modular microservice architecture, which contains failures if they were to happen. For example, a bug in the intraday algorithm can be contained without affecting the entire system. Combined with high-availability and fallback mechanisms, this structure significantly improves resilience.

Furthermore, smaller, independent modules with well-defined interfaces are far easier and faster to test and validate, directly addressing the critical constraint of limited testing capacities.

When a new market requirement emerges, such as the need for micro-auctions, it can be addressed by procuring a new, specialized module rather than attempting a complex, high-risk modification of the entire monolithic core. This makes the architecture inherently adaptable, ensuring it can evolve in lockstep with the physical grid. All modules having a standardized language to communicate would enable true "plug-and-play" functionality and simplifying integration across the entire European market. This foundational alignment and unification must be complemented by transparency and balanced access for both NEMOs and TSOs, as discussed in the next block. Without this, integration risks reinforcing existing opacity rather than addressing it.

Block 3

One scalable, secure, hybrid communication interface

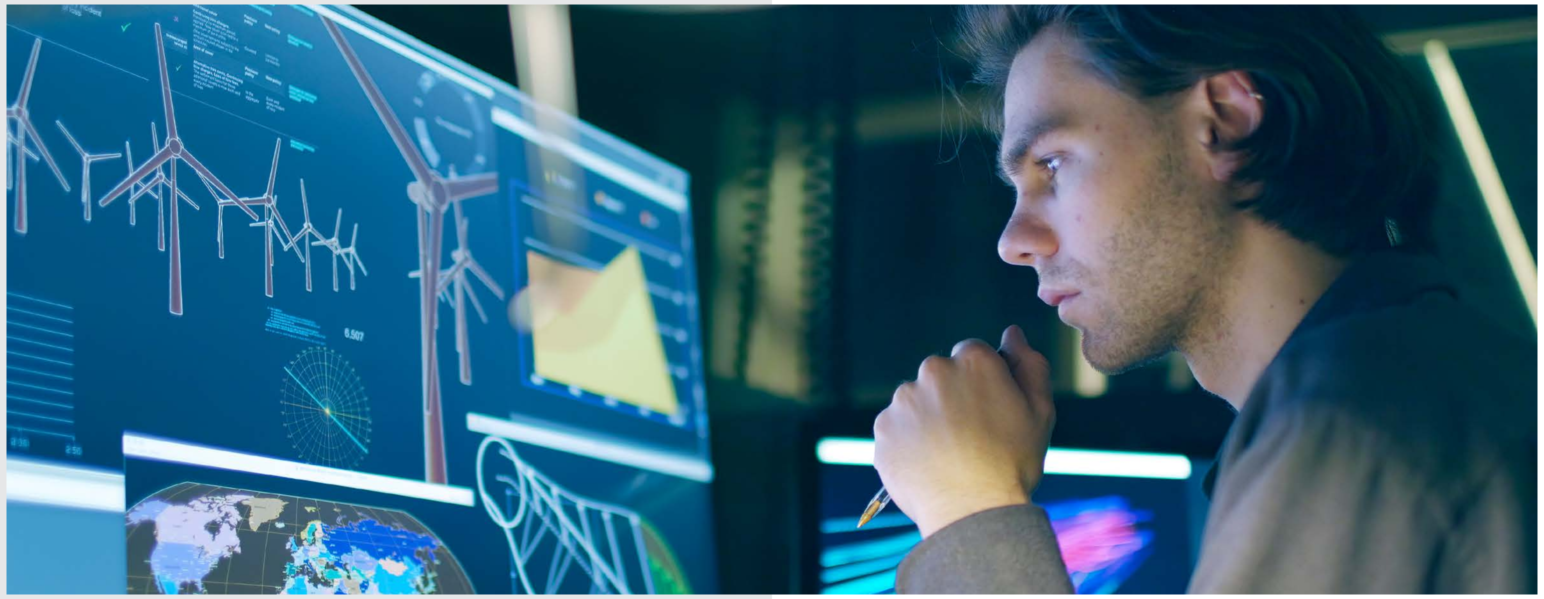
Status Quo: The communication between TSOs, Regional Coordination Centres (RCC), NEMO local trading systems on the one hand, and Euphemia and XBID modules on the other, relies on fragmented infrastructures, varied networks, and inconsistent security measures, heterogeneous data formats, and communication protocols. This directly risks turning throughput, latency, and incident handling into systemic bottlenecks.

The current environment is a heterogeneous patchwork of different infrastructures, including the Orange Multi-Protocol Label Switching (MPLS) network used for Euphemia and XBID on the TSO side, and the Colt MPLS network used for DA system connections with NEMOs. National Internet Service Provider (ISP) links and bespoke TSO-NEMO gateways are also used. Each segment uses different encryption standards, authentication methods, and monitoring tools. Moreover, the auctions and continuous trading systems currently use a mix of different formats, such as CSV or JSON files, to send bids and identity checks, alongside varied communication methods like APIs, File Transfer Protocol (FTP) or/and E-Mail across platforms such as EUPHEMIA/PMB and XBID (Shared Order Book (SOB), Capacity Management Module (CMM), Shipping Module (SM)).

This fragmentation creates systemic bottlenecks in throughput, latency, and incident handling, while expanding the cybersecurity attack surface and introducing multiple single points of failure[7].

Future Vision: A modular IT-Architecture is only viable if its components communicate seamlessly. The solution consolidates all market coupling communications onto a one secure private backbone, such as ENTSO-E's Private Communication Network (PCN) or a similar high-assurance solution.

- **A Unified Market Interface:** A single, versioned "front door" for all market interactions should be established using standardized protocols like the Electronic Communication Platform (ECP) and ENTSO-E Data eXchange (EDX) and message contracts running over the secure backbone. This approach removes integration variance, increases throughput headroom, and simplifies operations. To



achieve this, message contracts, covering schemas, sequencing, and acknowledgements, will be standardized alongside identity management systems (such as Public Key Infrastructure (PKI) and Single Sign-On (SSO) and endpoint lifecycle procedures. The result is a single, unified interface for both auction and continuous trading processes, allowing them to function cohesively while supporting their unique market rules[8].

- **Secure Traffic Isolation:** Using modern networking techniques such as Virtual Private Clouds (VPCs), Virtual Routing and Forwarding (VRF) different types of traffic, like day-ahead and intraday, can be securely isolated while sharing the same physical backbone. This enables the central enforcement of critical policies for latency, Quality of Service (QoS), and encryption, ensuring that performance and security are managed consistently across all market activities.

- **Integral, Layered Security:** Security must be integral to the design, followed by Secure-by-Design principles.

- **Encryption and Access Control:** All connections will be encrypted using robust standards like Transport Layer Security (TLS) 1.3 or Internet Protocol Security (IPsec), managed via a central PKI. Access will be governed by Zero Trust principles for all users and systems, ensuring that every connection is authenticated and authorized.

- **Identity Governance and Lifecycle Management:** Beyond Zero Trust, the system must implement a unified identity governance framework. This includes automated onboarding and offboarding via a System for Cross-domain Identity Management (SCIM), role-based access control (RBAC), and policy-as-code for compliance enforcement.

- **Threat Mitigation:** Micro-segmentation will restrict lateral movement in case of a breach, while intrusion detection and prevention systems provide active defence against threats.

- **Centralized Monitoring:** A central Security Operations Centre (SOC) will continuously monitor telemetry on network health and anomalies. This SOC will be tightly integrated with predictive monitoring and incident resolution systems to ensure both secure communication and resilient operations.

The onboarding and offboarding of TSOs, NEMOs, and other entities must follow a standardized blueprint. Security benchmarks will be verified prior to connection using Policy-as-Code. To maintain compliance, regular penetration tests and audits aligned with NIS2, ISO 27001, and IEC 62443 will be conducted, supported by continues compliance monitoring. These compliances must be codified into automated checks within Continuous Integration (CI) / Continuous Deployment (CD) pipelines.

This unified approach delivers strategic advantages by driving profound efficiency and enabling advanced automation. Unifying the data repository, API layer, and communication channels creates a single source of truth with clean, consistent, high-volume data, which is essential for intelligent systems such as AI-driven trading and advanced operational monitoring. This standardization also streamlines integration and scalability; a unified contract for schema, authentication, and data envelopes simplifies the onboarding of new participants, reduces the need for specialized connectors, and supports greater scalability through mechanisms like parallel data lanes.

While these benefits are substantial, the strategy also acknowledges and manages the inherent challenges. Migrating legacy interfaces to this unified model requires significant coordination and technical effort, and centralizing connectivity heightens security exposure. This risk must be actively managed through the strict network segmentation and continuous, vigilant monitoring embedded in the security design.

7. ACER. (2025). Cybersecurity benchmarking guide. https://www.acer.europa.eu/sites/default/files/documents/Other%20Documents/ACER-cybersecurity-benchmarking-guide-2025.pdf
8. Gyarmati, T., & Krajcs, J. (2023). European Market Coupling – Milestones in the work in progress [Presentation]. Hungarian Energy and Public Utility Regulatory Authority. https://erranet.org/wp-content/uploads/2023/04/MEKH_Market_coupling_Krajcs_230428_v2.pdf

System Design for High Availability

Block 4

Multiple high-availability production environments with automatic failover for resilience.

Status Quo: Current market systems operate on fundamentally different architectures: SDAC and IDAs rely on decentralized Euphemia instances, while continuous trading runs on a centralized, dual-homed XBID platform.

Auctions require multiple NEMOs to maintain dedicated infrastructure and teams, while NEMOs run the Euphemia algorithm concurrently, creating a multi-active environment where numerous instances process market data simultaneously on dedicated, certified hardware. Failover between these instances is currently manual rather than automated. Continuous trading faces performance strain due to growing algorithmic trading volumes, leading to costly upgrade cycles. In a market where any lapse could cause cascading disruptions to grid stability, this fragmented approach requires review.

Future Vision: High availability must be a core design principle, architected into the system from the ground up. The system must be able to automatically and instantly handle failures without human intervention[9]. This is achieved by:

- **Geographically Dispersed Active-Active Environments:** Two or more full-scale, production-grade environments will operate in geographically separate locations, leveraging current TSO datacentre investments. Each site will be fully capable of clearing auctions and sustaining intraday trading, with traffic managed via a secure, unified private backbone using Anycast routing and synchronous replication.

- **Automatic, Policy-Driven Failover:** Failover will be triggered automatically by multi-layer health checks that monitor everything from network connectivity to API health and the liveness of critical data feeds.

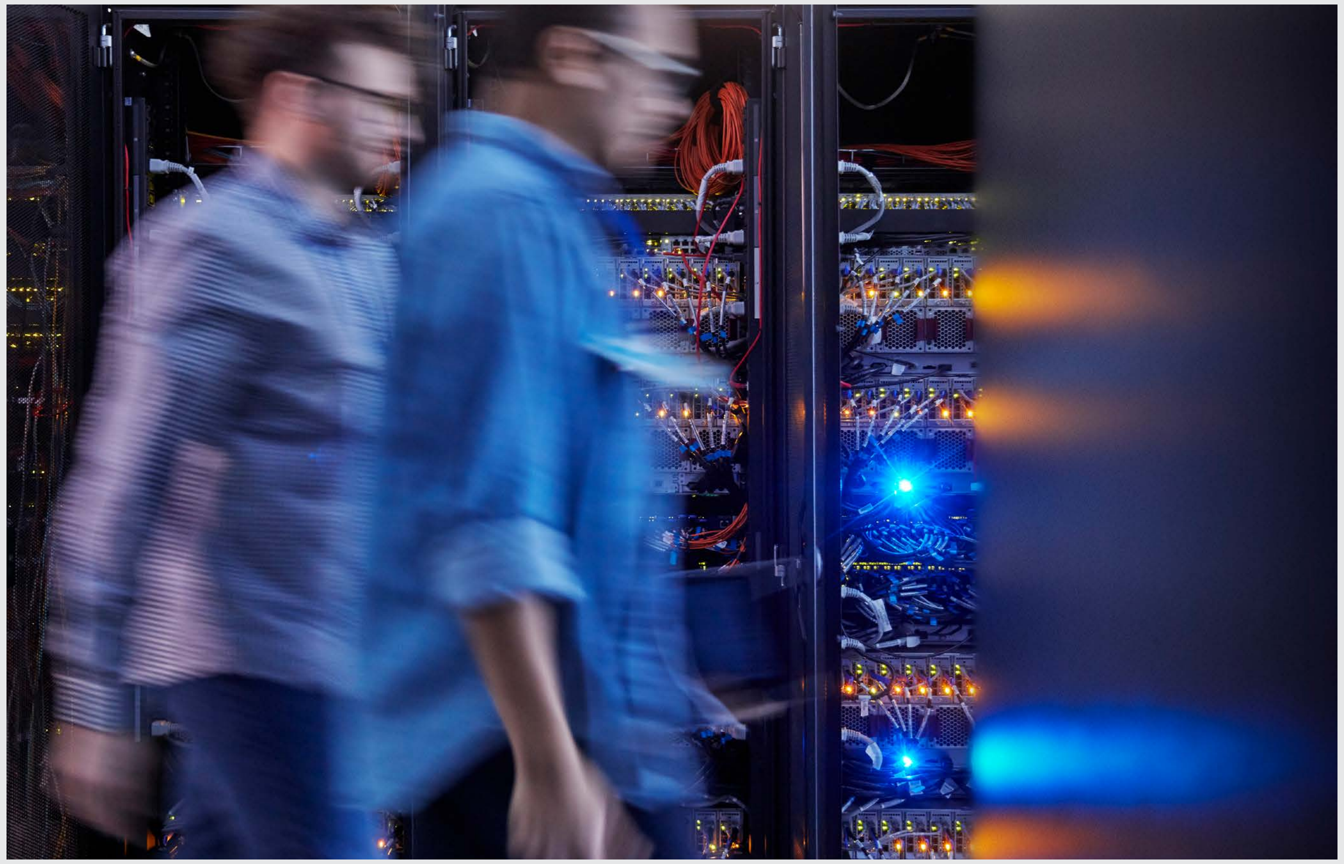
- **State Management for Coupling Outcomes:** For processes like day-ahead auctions, input snapshots (orders, network constraints) will be distributed to all sites simultaneously, allowing shadow sites to compute in parallel and be ready for an instant takeover. For continuous intraday trading, an event-sourced state with conflict-free replication will ensure that a newly promoted site can resume matching precisely where the failed site left off, with no risk of data loss or double execution.

- **Disaster Recovery and Business Continuity:** Beyond high availability, the IT-Architecture must define explicit Recovery Point Objectives (RPO) and Recovery Time Objectives (RTO). Automated failover across geo-redundant sites, combined with continuous replication and chaos engineering, ensures resilience against catastrophic failures. Regular Disaster Recovery (DR) drills and compliance audits will validate readiness.

- **A Standardized Fallback Communication Channel**: Business continuity will rely on a robust, standardized fallback channel running exclusively on the secure private backbone, never on the public internet. This channel will use resilient message queuing and be governed by a predefined playbook. Automated, regular chaos testing will ensure readiness.

This proactive, automated, multi-site resilience transforms operations: human operators evolve from manual firefighting to orchestrating automated systems, fine-tuning predictive models, and addressing only complex, novel incidents. Continuity becomes a predictable, engineered outcome.

9. ENTSO-E. (2024). Technical report on resilience in market communication. https://www.entsoe.eu/publications/general-publications/annual-report/



Algorithm Transparency and System Integrity

Block 5

Operational transparency and accountability

Status Quo: As Europe's grid becomes increasingly weather-dependent and variable, market coupling algorithms have become critical infrastructure. However, TSOs and RCCs currently lack full visibility into the source code and internal logic of proprietary systems such as Euphemia and XBID. While inputs and outputs bids, prices, schedules are accessible, the transformation process remains opaque. This gap limits operator's ability to validate outcomes, anticipate stress behaviour, and manage risks proactively.

Without transparency, TSOs cannot effectively model, simulate, or prevent failures, leaving them in a reactive posture. As trading becomes more dynamic with high-frequency and AI-driven strategies, the inability to understand algorithmic behaviour increases the risk of market instability with potential physical consequences for the grid. It also introduces an accountability challenge: TSOs are legally responsible for grid stability but cannot fully verify or explain algorithmic decisions, while vendors remain insulated by contractual boundaries, consolidating opacity rather than resolving it.

In addition, there has been growing criticism by stakeholders, including market participants, regulators and policy makers about the "black box" nature of the algorithms, and entry barriers of new market participants.

Future Vision: This misalignment between operational security and proprietary control underscores why foundational alignment and unification in the previous blocks must be paired with transparency. Without this, integration simply consolidates opacity rather than resolving it. The solution is to establish a mandatory policy of operational transparency for all critical market-clearing algorithms. The complete mathematical formulation, objective functions, constraints, and key operational parameters are fully documented and accessible to TSOs and regulators. The system must be architected from the ground up to produce reproducible and fully auditable results, transforming the "black box" into a "glass box".

This transparency is the key to enabling proactive risk management and high-fidelity simulation. With complete access to the algorithm's detailed formulation, TSOs can build robust, validated simulation environments to stress-test the market's behaviour against a wide range of plausible and extreme scenarios as discussed in further blocks. They can model the impact of geopolitical shocks, severe weather events, or the grid-wide effects of new, large-scale renewable generation and storage assets coming online. This capability is transformative, moving the TSO from a reactive to a proactive risk management posture. It allows them to identify potential instabilities before they manifest in the live market and implement mitigating measures, thereby ensuring that market outcomes remain aligned with physical grid security constraints.

An open-standard, transparent algorithm closes the accountability gap and builds enduring trust[10]. It allows for the independent verification of any market result. In the event of a dispute or an unusual outcome, TSOs can use the public formulation to replicate the calculation and understand the precise chain of logic that led to the result.

Ultimately, transparency empowers TSOs to ensure that the market-clearing algorithm, a tool designed primarily for economic optimization, does not inadvertently compromise the physical security of the power grid. It provides the critical layer of oversight necessary to validate that the algorithm's behaviour is consistently aligned with the TSO's primary and non-negotiable mandate: maintaining a secure and reliable supply of electricity for all of Europe.

10. ENTSO-E. (2025). Consultation on Transparency Frameworks. https://consultations.entsoe.eu/

Performance-Driven Requirements Management

Block 6

Future European DA and ID system and requirements management must prioritize scalability, flexibility, and performance. This focus must be underpinned by factual data and analysis, to ensure future-proof operational resilience of the entire SDAC/SIDC ecosystem[11]

Status Quo: Scalability, flexibility, and performance should be the guiding principles for future European DA and ID systems and requirements management. However, current practices remain fragmented and constrained by the technical divide between auctions and continuous trading. Moreover, the complexity of requirements management is increased by different system management principles between Euphemia and XBID platforms. Euphemia relies heavily on Price Coupling of Regions (PCR) Matcher and Brokers (PMBs) owned by PCR NEMOs, with developments split between market coupling and price/market processes inside the NEMO forum. Multiple committees and forums contribute to maintaining a level playing field. XBID follows a different process, delivered by a third party. However, there are dependencies in implementations between auctions and continuous trading systems.

Future Vision: Performance and scalability must become the central lens through which all system requirements are managed.

- **Proactive Requirement Definition:** Future performance requirements will be defined based on regulatory mandates, empirical monitoring data, results from load and stress tests, major incident analysis, and forward-looking simulations using digital twins and predictive analytics.

- **Performance Roadmap:** A multi-year roadmap will embed scalability and performance requirements into all planning cycles. This includes defining specific targets, integrating continuous performance testing into CI/CD pipelines, and applying scalability patterns such as horizontal scaling and sharding.

- **Data-Driven Prioritization:** Establishing a formal framework for assessing the performance impact of any proposed change. This assessment must be based on measurable data from simulations in the staging environment and should quantify or monetize impacts on factors like security of supply, market efficiency, and regulatory compliance. This shifts requirements management from being reactive and consensus-driven to being proactive and evidence-based. These factors should be evaluated using a weighted scorecard, with all elements - except regulatory compliance - monetized or quantified on a unified and comparable scale, ensuring objective and consistent prioritization. Latency, throughput, and resource usage simulations will provide empirical evidence, ensuring decisions are objective and evidence based. An automated decision matrix will classify features as performance critical.

Institutionalizing performance and scalability as core priorities will eliminate today's fragmented approach and deliver systemic resilience.

11. NEMO Committee. (2024). CACM cost report 2024: Single Day-Ahead Coupling – Scalability and performance (pp. 15–22). https://www.nemo-committee.eu/assets/files/cacm-cost-report-2024.pdf

Continuous Integration and Production-like Staging Environment

Block 7

Harmonized continuous integration and continuous deployment with automated tests, production like staging, and rollback capabilities

Status Quo: The auctions and continuous trading platforms evolved from separate initiatives with different architectures, resulting in misaligned release cycles. This slows onboarding of new parties, integration of bidding zones, and implementation of market design changes. Meanwhile, market evolution outpaces system upgrades, leaving stakeholders reactive.

Current testing approaches rely heavily on manual processes and are constrained by infrastructure and resource limitations. Limited testing capacity hampers preparation and execution of test cases, while fragmented resourcing stretches release cycles over several months. The ecosystem lacks a standardized mechanism for deploying urgent fixes, such as security patches or bug resolutions, within days or weeks instead of months. As a result, new releases cannot be validated under realistic load conditions before go-live, exposing the market to preventable risks.

Future Vision: While previous blocks define the system's logical, modular blueprint, this unified quality assurance framework provides the operational machinery to package, deploy, test, and manage these modules safely and at speed. The framework consists of four integrated steps:

1. The CI/CD Pipeline (Packaging and Deployment): The process begins with Continuous Integration and Continuous Deployment (CI/CD), where each software module is packaged into a standardized, self-contained artifact using containerization technologies (e.g., Docker). This ensures each component is immutable (using signatures) and behaves identically across all environments. These containers are managed by an orchestration platform (e.g., Kubernetes), which automates their deployment, scaling, and lifecycle, making the system more resilient and easier to maintain.

This foundation enables modern deployment strategies like Blue-Green and Canary releases. In a Blue-Green release, two identical environments are used to allow for a quick and safe switch if something goes wrong. In a Canary release, the update is first rolled out to a small group of users to allow for early issue detection. These strategies, combined with automated rollback mechanisms tied to monitoring systems, allow changes to be introduced gradually and safely, reducing the risk of exposing the entire market to a faulty update.

2. The Digital Twin Environment (Validation Arena): The CI/CD pipeline deploys new software not to a simplistic test server, but into a "Digital Twin" of the live DA and ID stack. This production-like staging environment is a high-fidelity replica of the production system, using the same codebase, parameterization, market time units, and interfaces[2,7]. This serves as the critical validation arena, ensuring that tests are conducted under conditions that are indistinguishable from the live market, thereby eliminating the risk of "Environment Drift".

3. The Data Foundation (Fuel for Testing): This entire process is powered by a centralized data lake, which combines the flexibility of data lakes with the management features of traditional databases. Leveraging technologies like Delta, Iceberg, or Hudi, this environment serves as a single source of truth where TSOs and NEMOs can consolidate historical market data alongside critical external information like weather forecasts and grid topologies. This provides the petabyte-scale historical and synthetic datasets required for comprehensive and realistic testing.

4. The Validation Engine (Testing Process): Within the Digital Twin, and using data from the data lake, a rigorous and automated validation engine is executed. This engine can perform "historical replay" to replicate past trading timelines and detect regressions, and it can inject "synthetic stress scenarios", such as renewable energy surges or grid bottlenecks, to test the system's resilience at its limits. Automated frameworks like Robot Framework and PyTest validate functional behaviour and data consistency, while load-testing tools like Locust or JMeter measure throughput, latency, and algorithmic responsiveness under extreme load.

This integrated infrastructure allows TSOs and NEMOs to confidently verify that any new release or algorithm change can handle real-world load and grid-sensitive behaviours, mitigating operational risk before impacting the live market. Giving TSOs and NEMOs access to a true production-like environment would enable end-to-end detection of defects, performance bottlenecks, and unexpected interactions, without risking real market outcomes.

2. NEMO Committee. (2025). CACM Annual Report 2024: Single Day-Ahead and Intraday Coupling. https://www.nemo-committee.eu/assets/files/cacm-annual-report-2024.pdf
7. ACER. (2025). Cybersecurity benchmarking guide. https://www.acer.europa.eu/sites/default/files/documents/Other%20Documents/ACER-cybersecurity-benchmarking-guide-2025.pdf

24/7 Automated Operations, Monitoring, and Incident Management

Block 8

Proactive monitoring with automated AI-based operations, incident resolution, predictive analytics.

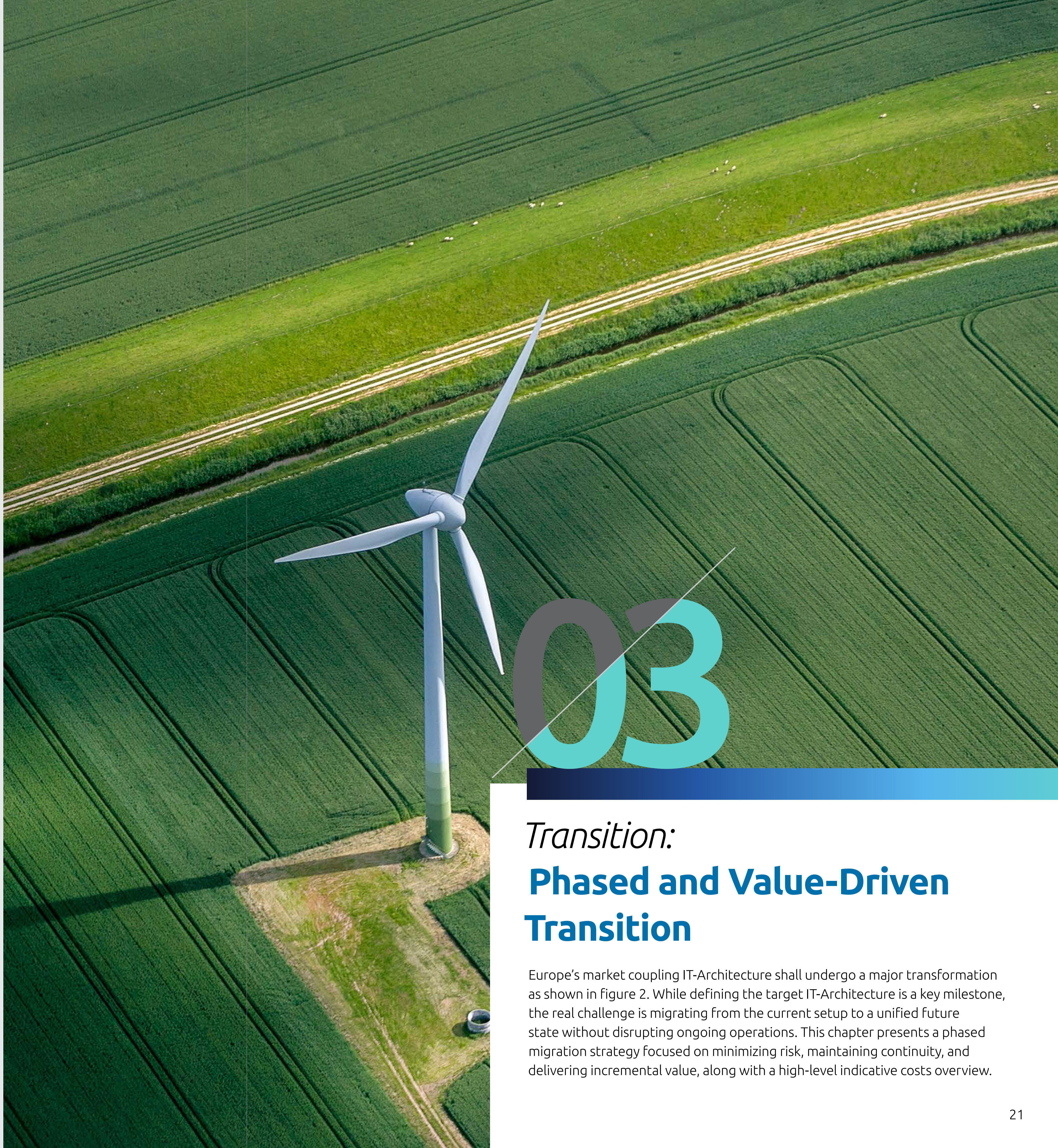
Status Quo: Currently, monitoring relies on static thresholds and manual dashboards, which only identify issues after they have already impacted trading or clearing. This approach fails to capture pre-transactional risks like weather forecast inaccuracies (drifts), grid model mismatch, or trading system overload. In future spot markets, even minor issues like delayed order ingestion, slower matching, or stalled capacity feeds could quickly cascade into price distortions, failed clears, and large-scale redispatch needs. Regulators, market participants and grid operators will expect continuous availability, with incident response times measured in seconds rather than minutes or hours.

Future Vision: A paradigm shift is needed from reactive monitoring to proactive, automated oversight powered by predictive analytics and intelligent alerting, that identifies anomalies before they affect market outcomes to limit such situations as market outages or latent degradations (e.g., delayed order ingestion, slow matching, stalled capacity feeds). This system will leverage a centralized data lake consolidating operational telemetry, contextual market data (e.g., renewable forecasts, demand peaks), and deployment metadata from the CI/CD pipeline. This unified dataset enables:

- **AI-Enhanced Capabilities:** Advanced tools will help operators understand what happened by analysing unstructured data like logs and incident reports. They can extract insights, summarize root causes, and suggest mitigation steps based on historical knowledge and technical documentation.

- **Predictive Analytics:** Machine learning models will be trained to identify complex patterns and subtle anomalies that precede failures, allowing operators to intervene before market outcomes are affected.

This turns operational noise into context-rich, actionable intelligence, empowering operators to maintain stability even during extreme market conditions.



03

Transition:

Phased and Value-Driven Transition

Europe's market coupling IT-Architecture shall undergo a major transformation as shown in figure 2. While defining the target IT-Architecture is a key milestone, the real challenge is migrating from the current setup to a unified future state without disrupting ongoing operations. This chapter presents a phased migration strategy focused on minimizing risk, maintaining continuity, and delivering incremental value, along with a high-level indicative costs overview.

Figure 2 below illustrates the modular target reference IT-Architecture for future market coupling systems. It depicts layered components ranging from infrastructure and connectivity to data management, integration, and core algorithmic services, ensuring interoperability among TSOs, NEMOs, and RCCs.

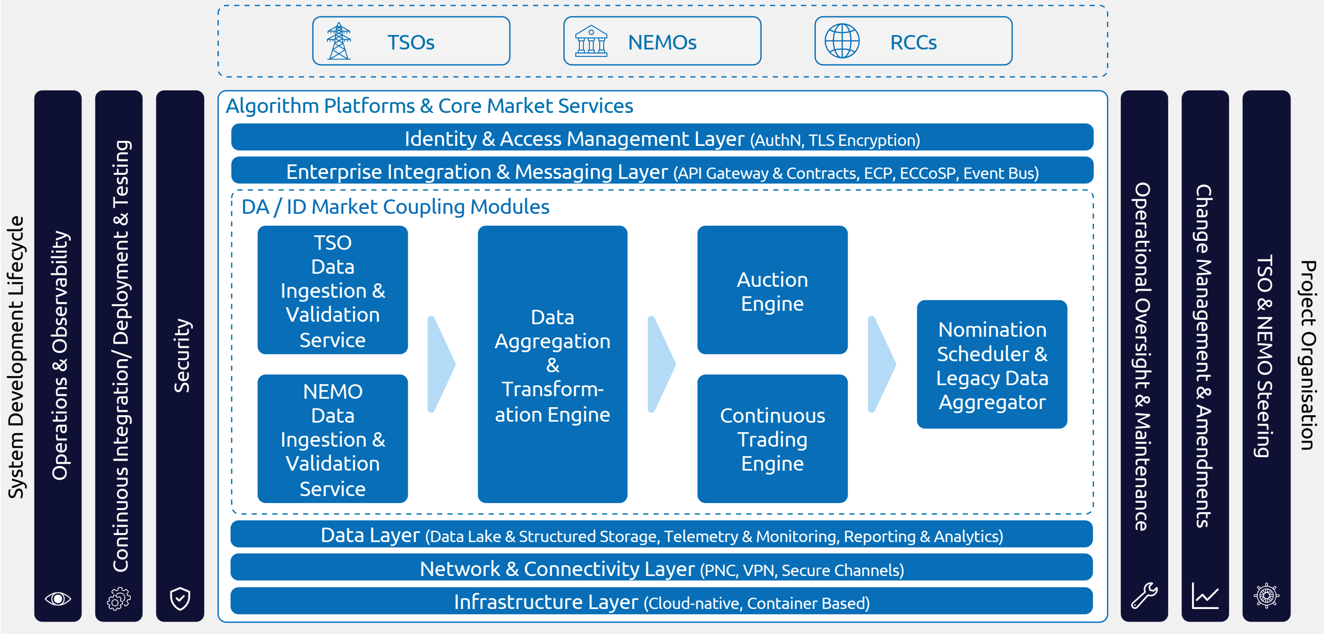


Figure 2: Modular Target Reference Architecture

The transition and the budget could be structured into three phases, with a significant upfront investment in on-premises hardware followed by recurring operational and personnel costs.

We expect a significant frontloaded capital investment required during the initial phase, followed by a smoothening toward operational and personnel expenditures in later stages. In addition, the cost projections incorporate extended costs for sustaining the existing physical infrastructure of current spot markets throughout the transition period, ensuring continuity and market stability. For the sake of simplicity and predictability the Miscellaneous Charges Order (MCO) fee for market participants can be fixed at 1 ct/MWh, on top of exchange and clearing fees.

Phase 1 (Years 1–4): Unifying Communications and Operations

The first phase is dedicated to stabilizing the system's outer layers to immediately reduce operational risk and establish a resilient foundation, as well as upfront investment into creating a modular IT-Architecture. This period marks the peak of capital expenditure as new on-premises infrastructure is deployed in parallel with existing legacy systems. The core objective is to create a unified, secure, and highly available environment that supports seamless operations and proactive monitoring.

A key milestone is the implementation of a **Unified Communication Backbone**, which will replace the current fragmented mix of MPLS lines and national links with a single, secure, and scalable private network. This standardization ensures consistent market messaging across all regions.

To ensure business continuity, two geographically separated, active-active on-premises datacentres will be deployed with automatic failover capabilities. A third site will serve as a production-like staging environment for testing and deployment. This setup, comprising at least two production sites and one testing site, aims to provide a unified, secure, and highly available infrastructure that supports seamless operations, proactive monitoring, and parallel runs during the transition.

The phase initiates **Monolithic Refactoring**, of the Euphemia and XBID monoliths. Non-core functionalities, such as user management, trade reporting and others, will be rebuilt as independent modules on the new platform, paving the way for a more modular and scalable architecture. The rebuilding of core coupling and matching logic will also commence by specialized teams.

Finally, the phase will deliver a Harmonized CI/CD Pipeline, enable automated, quality-controlled software deployments and industrialize the release process. This ensures faster, more reliable updates and a standardized approach to development across the organisation, and, importantly, the later rollout of the new IT market coupling paradigm using production-like inputs.

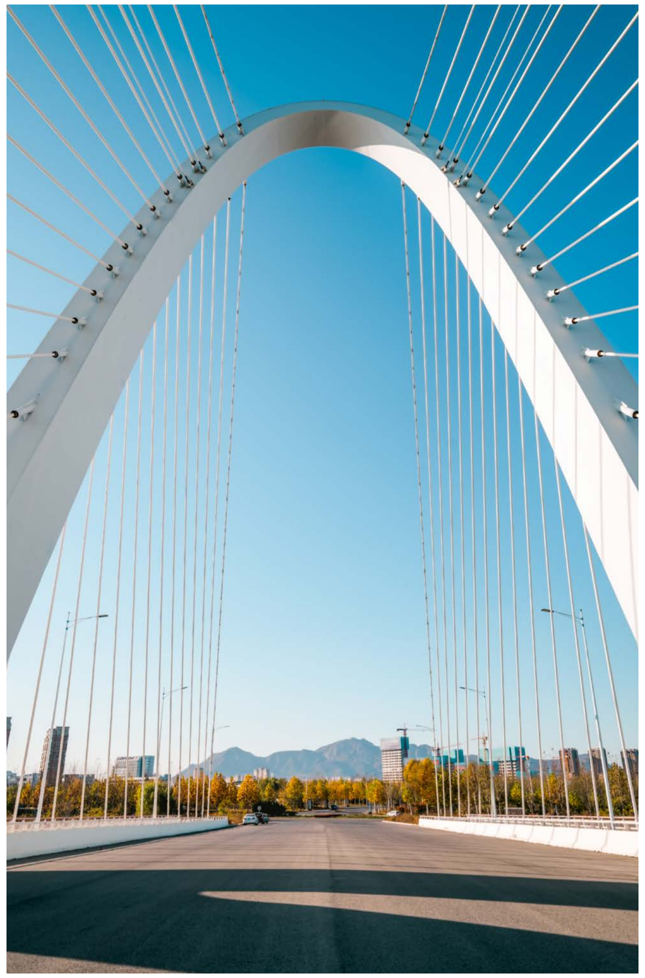
Phase 2 (Years 4–7): Unifying Data and Interfaces

With the foundational infrastructure in place, the second phase shifts focus to harmonizing data models and application interfaces. The goal is to create a single source of truth and a unified "front door" for all market interactions. This stage is primarily personnel-intensive, leveraging the platforms established in Phase 1 to manage risk while driving integration.

A central component of this phase is the **Central Data Lake and Common Data Repository**, both of which will consolidate fragmented data sources into a single platform. This will eliminate existing silos, standardize market data, and enable comprehensive cross-market analytics and regulatory oversight, and enable observability established in this stage.

To simplify external interactions, a **Common API Layer** will be developed. This unified, versioned, and secure API gateway will abstract the complexity of legacy systems, providing a single, consistent point of access between modules, and for the relevant external parties.

Operational visibility will be transformed with the **Unified Observability Platform**, an AI-enhanced monitoring solution providing a holistic, end-to-end view of system health. This shift moves operations from reactive troubleshooting to proactive management.



Phase 3 (Years 6–7): Merging and Preparing for Future Innovations

At least one production-like testing site will be used for at least 6 months parallel runs for testing and deployment of the new paradigm into the production.

At the same time, Market Coupling Innovation Lab: Funding is set aside for the establishment (capital expenditure) and operation (operational expenditure and personnel) of a dedicated lab to prototype and validate future market solutions in a controlled, vendor-neutral environment.

Overview of Anticipated Costs

The transformation is structured across three phases, each with distinct cost drivers and objectives. All cost estimates are indicative and based on current assumptions. Actual costs may vary depending on vendor pricing, implementation choices, and infrastructure scope. Especially if more than one production-like staging environment is built. The subsequence's high-level cost estimates combine empirical benchmarks with estimated efforts derived from interviews conducted with the TSOs.

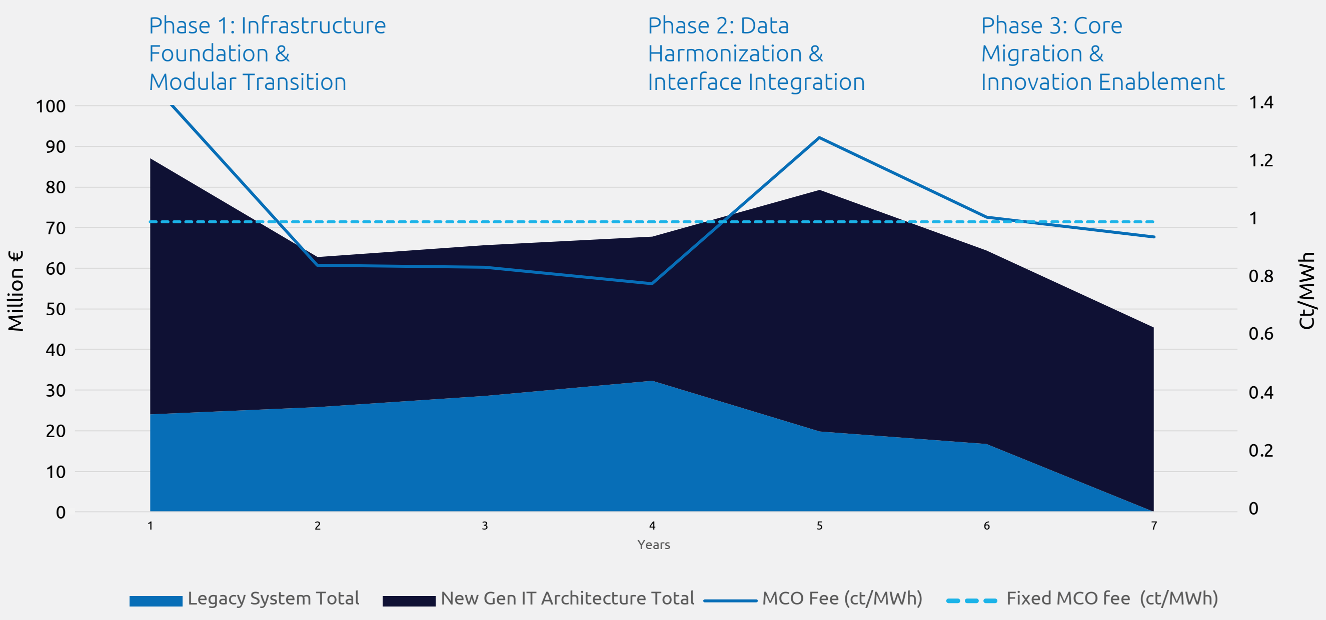


Figure 3: Exemplatory Average Cost Evolution and MCO Fee Impact

The total projected cost estimates range approximately between €300 - €350 million over seven years, which is visualized in the graph above. The average costs for the current system and for the implementation of the new one are cumulated.

Phase 1 (Years 1–4): Infrastructure Foundation and Modular Transition; approx. €160M - €180M

This phase involves the highest capital expenditure, focused on building a high-availability, unified infrastructure. This includes costs for data centre hardware, covering servers, storage, and networking equipment for two production sites and one staging environment. Operational costs include colocation, power, and cooling. Additional expenses cover software licensing, network upgrades, and high-bandwidth connectivity.

Personnel costs are considered for funding a Central Platform Team of network engineers, Site Reliability Engineers and DevOps specialists. Key deliverables include a resilient communications backbone, CI/CD pipelines, modularization of non-core Euphemia/ XBID components, and reestablishment of algorithmic logic.

Phase 2 (Years 4–7): Data Harmonization, Interface Integration and National Implementation; approx. €100M - €120M

With the infrastructure in place, the focus shifts to the data and application layers for building a unified data lake and common API layer, with additional operational costs for licensing specialized platforms. Personnel remain the largest cost category, supporting development teams working on data architecture, API development, and refactoring monolithic applications.

Infrastructure expansion continues with recurring budgets for scaling server and storage capacity. National integration of market participants is also supported.

Phase 3 (Years 6–7): Core Migration and Innovation Enablement; approx. €40M - €50M

This phase focuses on the migrating of core matching algorithms for parallel runs and additionally on the funding of an Innovation Lab to support experimentation and future enhancements.

Cross-Cutting Costs

Across all phases, ongoing costs include cybersecurity, governance, and change management. A comprehensive Zero Trust security program will require annual funding for tools, audits and expert personnel to ensure compliance with regulations such as NIS2. Project governance will be supported by a central PMO or similar structure, with dedicated resources for training, stakeholder communication, and managing the human transition across dozens of organisations. Additional costs will arise from tenders, stakeholder engagement, and continuous monitoring.

04

Conclusion:

A Pragmatic Path to a Future-Proof European Electricity Market

The European single electricity market, a monumental achievement in economic and energy cooperation, has reached an inflection point.

The very IT-Architecture that enabled its success is now straining under the immense pressure of the energy transition. Exponential growth in transactions, driven by the rapid expansion of renewables and the rise of automated trading, has exposed the fundamental limitations of the current fragmented, dual-stack system. The escalating complexity, operational risks, and resource constraints mean that incremental adjustments are no longer sufficient. A systemic, architectural transformation is now an urgent necessity to safeguard Europe's energy security and achieve its ambitious decarbonization goals. This paper sets out a strategic direction for transforming the Market Coupling IT-Architecture into a robust, modular and adaptable platform.

In sum, the transition described here is not only a technical modernization but a strategic necessity. It is the opportunity to build a market coupling architecture capable of safeguarding stability, enabling innovation, and securing Europe's electricity markets against the challenges of the coming decades. With 32 TSOs and 17 NEMOs across 26 countries relying on SDAC and SIDC systems today, the stakes are continental in scale – and so too must be the ambition for Europe's future DA and ID IT-Architecture.

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Disclaimer

Following an assignment by the European Transmission System Operators (TSOs) involved in the SDAC and SIDC market coupling initiatives, Capgemini Invent has prepared a visionary, high-level study on the future IT-Architecture of market coupling (hereafter referred to as the “IT Study”). The IT Study was financed by the TSOs but independently conducted by Capgemini Invent, a globally renowned IT and strategy consultancy. While European TSOs provided detailed input and supported the review process, Capgemini Invent retained full decision-making authority over the content of the study. The study was developed in collaboration with Fraunhofer and Ponton. This publication summarizes the key findings. A full-length version of the study is available upon request. Before any further steps regarding the future IT-Architecture of market coupling can be taken, additional studies will be required. These should be conducted in collaboration with the NEMOs active in SDAC and SIDC and should include broader stakeholder engagement.

List of Abbreviations

AHC	Advanced Hybrid Coupling
AI	Artificial Intelligence
API	Application Programming Interface
BESS	Battery Energy Storage Systems
CCR	Capacity Calculation Region
CD	Continuous Deployment
CI	Continuous Integration
CMM	Capacity Management Module
DA	Day-Ahead
DR	Disaster Recovery
DSR	Demand Side Response
ECP	Energy Communication Platform
EDX	Energy Data eXchange
ENTSO-E	European Network of Transmission System Operators for Electricity
FB-IDCT	Flow-Based Intraday Continuous Trading
FB-MC	Flow-Based Market-Coupling
FTP	File Transfer Protocol
ID	Intraday
ID CZ GCT	Intraday Cross-Zonal Gate Closure Time
IDAs	Intraday Auctions
IDCT	Intraday Continuous Trading
IPsec	Internet Protocol Security
ISP	Internet Service Provider
LTS	Local Trading Solutions
MCO	Miscellaneous Charges Order
MCSC	Market Coupling Steering Committee
MPLS	Multi-Protocol Label Switching
NIS2	Network and Information Security Directive 2
PCN	Private Communication Network
PCR	Price Coupling of Regions
PEVF	Pan-European Verification Function
PKI	Public Key Infrastructure
PMB	PCR Matcher and Broker
PMO	Project Management Office
QoS	Quality of Service
RBAC	Role-based access control
RCC	Regional Coordination Centre
RPO	Recovery Point Objectives
RTO	Recovery Time Objectives
SCIM	System for Cross-domain Identity Management
SDAC	Single Day-Ahead Coupling
SIDC	Single Intraday Coupling
SM	Shipping Module
SOB	Shared Order Book
SOC	Security Operations Centre
SSO	Single Sign-On
TLS	Transport Layer Security
VPCs	Virtual Private Clouds
VRF	Virtual Routing and Forwarding
XBID	Cross-Border Intraday Market

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PONTON is a specialist software and consulting company focused on European energy markets, from trading to settlement and transmission. PONTON was founded in 2001 and is based in Hamburg. PONTON brings creative ideas to trading, grid operation and system design, and the PONTON team knows how to operate systems and platforms securely, efficiently and with high performance. PONTON is privately held and managed by its founders, large enough to deliver, but small enough so that clients get management attention. The track record of its service teams results in high customer satisfaction. PONTON is committed to the highest standards of security and compliance with applicable regulation; and is a key contributor to packages like REMIT and

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