The Potential for Innovation in a Decentralized, Asynchronized Power Grid

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Abstract

Using the SAFErGrid concept as an illustrative case, this paper argues that reorganizing the grid into an internet-like, layered architecture of autonomous sub-grids connected by smart Energy Routers opens three related channels for innovation. First, it may stimulates technological innovations that provides a will complement current efforts at power grid upgrading. Second, it may facilitate new business models, through its Energy Application Layer - which can function as a platform on which third parties can build dynamic-pricing, quality-of-service, and peer-to-peer trading services. Third, it allows investments in energy buffers (BESS) and smart routers to be evaluated as real options on grid flexibility. The paper shows how these three perspectives implies a promising potential for innovation in a decentralized, asynchronized decentralized power grid.

Keywords: Power grids, renewables, innovation, energy economics, business models

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1 Introduction

Europe's transition toward a renewables-intensive electricity system[1] is placing growing strain on a synchronous alternating-current (AC) grid designed for a different era. Grid operators face a threefold challenge: maintaining an instantaneous balance between supply and demand, preserving enough inertia to slow the rate of change of frequency, and avoiding transmission congestion that could jeopardize both (Ulbig et al., 2014; Stankovski et al., 2023; Titz et al., 2023). The conventional response — building more transmission and distribution capacity — is capital-intensive[2] and slow.

Among the proposals for modifying the centralized and synchronized AC covering Europe,[3] the SAFErGrid proposal[4] has made the radical case for an asynchronous, internet-inspired architecture that compartmentalizes the grid into autonomous sub-grids connected by intelligent Energy Routers (Schwarz et al., 2026) . The economic case for such a proposal centers on how it resolves the balancing, inertia, and congestion problems described above, and on the resulting effects on prices and energy poverty- see for instance Naudé (2026b,c) and Naudé (2026a).

This paper, a companion piece to Naudé (2026b,c,a), adds to the economic case for such a proposal by arguing that decentralization of this kind is also, in its own right, a source of innovation. Three related arguments are developed. First, it is argued that the SAFErGrid architecture will require - and hopefully stimulate - a bundle of technological innovations — for instance in grid architecture, routing, stability metrics, and protocol design — that

[1]Between 1985 and 2025 the share of electricity supplied by renewables globally, and in Europe, doubled from respectively 17% to 34% and 21% to 42%. By 2024 the single largest source of electricity in the EU was renewables (solar, wind, hydro and biomass) - supplying 48% of the continent's electricity.

[2]For instance, the European Commission has indicated that "EUR 584 billion in investments are necessary for the electricity grids this decade" (EC, 2023, p.2).

[3]The Continental Europe Synchronous Area (CESA) is the largest synchronous grid in the world, covering 32 countries (Westphal et al., 2022; Alexandrin, 2025).

[4]The SAFErGrid project is supported by the European Research Council (ERC), see `https://cordis.europa.eu/project/id/101166783`

opens a genuine research and development agenda in its own right.

Second, a case is illustrated that by separating a physical "Energy Routing Layer" from a software-defined "Energy Application Layer," the SAFErGrid architecture creates a platform on which new business models — such as providing dynamic pricing, quality-of-service contracts, peer-to-peer trading — can be built by third parties.

Third, it is shown that the distributed buffers and routers that constitute the SAFErGrid can be seen as a decentralized portfolio of real options on grid flexibility — an asset class whose value increases with market volatility.

The remainder of the paper proceeds as follows. Section 2 briefly explains the SAFErGrid concept. Section 3 describes the technological innovation agenda embedded in the proposal. Section 4 develops the platform and business-model perspective, drawing on multi-sided platform theory. Section 5 develops the real options perspective, applying an options-pricing framework to the value of decentralized flexibility and to the systematic risk of the wider power system. Section 6 concludes.

2 The SAFErGrid Concept

This section provides a short description of the core of the SAFErGrid concept. For a more detailed description the reader is referred to Schwarz et al. (2026).

The SAFErGrid concept rests on three linked proposals.

One is that the power grid is compartmentalized into autonomous sub-grids — labeled A-grids — each of which manages its own internal frequency and voltage and can in principle run on different technical standards (50 Hz, 60 Hz, or even DC) without requiring continent-wide synchronization.

A second is that smart Energy Routers act as gateways between A-grids, routing energy streams in a manner deliberately analogous to how routers direct data packets across the internet.

A third element of the proposal is that energy within this grid is managed according to what Schwarz et al. (2026) refers to as the AFSC principle: Aggregate locally, Forward to neighbors, Store in local buffers, or Convert to other carriers such as hydrogen.

As Schwarz et al. (2026, p.3) describe it, the Energy Routers are power-electronics devices that "decouple the a-grids and manage energy streams between them," enabling "a store-and-forward energy routing paradigm" that delivers energy from generators to end-consumers across A-grids as needed. This store-and-forward mechanism relies on distributed storage — batteries and super-capacitors — to create an energy buffer, so that any A-grid can receive, hold, and later forward energy, decoupling generation from consumption in time.

The architecture is organized in four layers, loosely modeled on the internet's Open Systems Interconnection (OSI) stack, summarized in Table 1.

Table 1: Proposed A-grid Architecture

Layer	Primary Function	Key Features
4. Energy Application Layer	Enables high-level services and business models.	Supports dynamic pricing, demand response, and power-on-demand services.
3. Energy Streaming Layer	Coordinates global energy balance across the grid.	Replaces traditional secondary and tertiary control; manages energy availability without overloading segments.
2. Energy Routing Layer	Physically forwards energy between neighboring A-grids.	Uses the AFSC principle (Aggregate, Forward, Store, then Convert) to move energy streams.
1. A-Grid Layer	Manages local power flow within a single subgrid.	Operates on existing technology and primary control principles; performs local balancing and energy distribution.

The layered separation reflected in Table 1 matters for the arguments developed in the rest of this paper: it is precisely because the plumbing (Layers 1–3) is separated from a programmable application layer (Layer 4) that new business models can be facilitated, in much the same way that separating physical network infrastructure from application software enabled the platform economy of the internet.

3 Innovations in the SAFErGrid Concept

Beyond its role in resolving balancing, inertia, and congestion problems, the SAFErGrid proposal embeds a distinct technological innovation agenda. As Europe transitions toward low-inertia, renewable-intensive electricity, the asynchronous architecture that Schwarz et al. (2026) propose is intended to reduce reliance on the costly annual grid reinforcements currently projected through 2050. Such a power grid design can save Europe substantial financial resources over the long run, the savings coming form the saved investments into infrastructure, such as grid expansion in form of copper lines.

The asynchronous model maximizes the use of existing infrastructure through flexible routing, rather than just extending transmission lines. It is however, a radical vision, and much will need to be done to realize the proposal. In particular, the proposal assume that critical technologies will be innovated and scaled up to provided critical solutions. This section identifies these future technologies to be on the to-do list for engineers and inventors.

The vision of the SAFErGrid is the compartmentalization of the grid into A-grids. Rather than connecting ever-larger synchronous zones through high-voltage direct-current (HVDC) links, as is the current European strategy (IRENA, 2019), the proposal breaks the grid down into small, autonomous asynchronous sub-grids. Each A-grid manages its own frequency and voltage internally, so a fault in one compartment is inherently isolated and cannot cascade into a continent-wide blackout. Because sub-grids are decoupled, they can also run different technical standards without requiring global synchronization.

This vision relies on a "Store-and-Forward" architecture. At the time of writing, this architecture lacks a standardized hardware and software ecosystem. Current power electronics (HVDC converters, inverters) are specialized and expensive. A-grids will need standardized, modular, and mass-producible bidirectional energy routers that can implement the AFSC principle.

In principle each A-grid would need at least one energy router to maintain local stability. Europe currently has approximately 4.5 million distribution substations.[5] This does not mean 4.5 million energy routers - which may be prohibitive expensive - smart energy routers that can be mass-produced do not yet exist at the continental scale envisioned. For this reason probably, Schwarz et al. (2026) proposes the energy routing layer where the energy router is located. Such a layered architecture, where routers interconnect regional or national grids, would reduce the costs. Nevertheless, if one considers similar functional equivalents in some sectors, such as Solid-State Transformers (SSTs), then the price tag of an energy-layered Energy Router may be high, in particular because of the need for relatively expensive high-performance semiconductors like Silicon Carbide (SiC) and Gallium Nitride (GaN) (Avraham et al., 2025).

Furthermore the *Energy Streaming Layer* (see Table 1) will require a robust communication protocol with the sub-millisecond deterministic latency required for electrical stability. While specialized protocols exist that meet these requirements - e.g. Time-Sensitive Networking (TSN), 5G/6G URLLC and the Precision Time Protocol - they are not yet deployed as a universal Internet of Energy standard (Satka et al., 2023; Taylor, 2025).

In the proposal of Schwarz et al. (2026) the concept of *Action Energy* is introduced as a novel metric used to quantify the energy required to maintain stability in a system where traditional physical inertia is absent. As the authors recognize, there are currently no commercial sensors designed to measure and broadcast Action Energy in real-time to coordinate decentralized

[5] See`https://www.eurelectric.org/in-detail/distributiongridsforspeed/`

subgrids. As such, the concept of Action Energy is currently a software-defined calculation, rather than a measure.

Finally , Grid-Forming (GFM) inverters will become more important as they provide Virtual Inertia (VI) using software to mimic the behavior of a spinning turbine (Brobbey et al., 2026). They are approaching commercial availability. For instance, Huawei's Fusion Solar 9.0[6] and Siemens' grid-forming solutions[7] are marketed specifically for grids where traditional stability is failing. The idea in the Schwarz et al. (2026) proposal is that large numbers these GFM inverters can work together in an asynchronous system-of-systems, without needing every device to be locked to the exact same 50Hz frequency. There is however, still a technological gap in terms of the standards, protocols, and high-speed coordination to make thousands of GFM inverters work together as a single, resilient continent-wide system.

The technological challenges described in this section are suggestions to inform the R&D agenda for the realization of asynchronous grids, as for instance proposed by SAFErGrid.

These challenges, together with the economic challenges outlined in the previous sub-section, implies that the roll-out of the SAFErGrid will have to be planned in stages, and that rather than replacing the existing synchronous grid in totally, the key elements of SAFErGrid will merge over time with the existing grid - particular to reap the economic benefits that such a form of decentralization and a-syncronicity can bring.

4 Facilitating New Business Models

Beyond the technological innovations - that will hopefully be triggered by the SAFErGrid initiative - that was described in the previous section, a further contribution of a SAFErGrid

[6]See : `https://solar.huawei.com/en/news/2026/fusionsolar-9-europe-launch/`

[7]See: `https://www.siemens-energy.com/global/en/home/publications/white-paper/download-grid-forming-converters.html`

to innovation lies in the new business models it can facilitate.

Because the top application layer sits above the physical layers described in Table 1, the asynchronous power system creates — in addition to the static market efficiencies associated with balancing, congestion, and pricing — dynamic efficiencies, in the sense of opening the door to new business creation. In principle, this layer can be opened to software start-ups and third-party providers building applications for energy efficiency and demand response, fostering a more competitive market that further drives down service prices.

Four broad areas of potential new business creation are explored from a theoretical point of view in this section: platform-based energy services, dynamic pricing and demand response, quality-of-service models, and peer-to-peer energy trading.

4.1 Platform-Based Energy Services

The functioning of platform-based energy services within an A-grid can usefully be examined through the lens of multi-sided platform theory and network economics. In this reading, the Energy Router acts as the platform provider, and the A-grid itself is the ecosystem in which diverse agents — prosumers, service providers, third-party applications — interact. As in a Stackelberg game, the Energy Router (the platform) is the leader, and prosumers (the users) are the followers.

For a consumer i, utility (U_i) is derived not just from energy consumption q_i, but from the quality of service (QoS) of the energy stream. For instance, in the A-grid, consumers do not buy power; rather they subscribe to tasks - such as "charge my EV by 7 AM":

$$U_i(q_i, \theta_i, p) = v_i(q_i, \theta_i) - p \cdot q_i + \gamma \cdot N_{ext} \tag{1}$$

Where $v_i(q_i, \theta_i)$ is the value function, with θ_i the QoS requirement (e.g., "guaranteed" vs. "best-effort"); p is the dynamic price of the energy stream and $\gamma \cdot N_{ext}$ the network externality. This is because in an A-grid, the value for a user increases as more peers join the platform.

To find the demand function, the first-order condition with respect to q_i is:

$$\frac{\partial U_i}{\partial q_i} = \frac{\partial v_i(q_i, \theta_i)}{\partial q_i} - p = 0 \tag{2}$$

Solving for q_i, and assuming a standard quadratic value function $v_i(q) = \alpha_i q - \frac{1}{2}\beta_i q^2$, the demand function becomes of the consumer i is:

$$q_i^D(p) = \frac{\alpha_i - p}{\beta_i} \tag{3}$$

From which the aggregate demand for the A-grid is the sum of all individual demands: $Q^D(p) = \sum q_i^D(p)$.

In Schwarz et al. (2026) the energy router acts as a platform. To sustain its operation - buffering and routing - it imposes a charge τ per unit of energy transferred. Hence, the price paid by the consumer is $p_C = p^* + \tau$, and the price received by the seller is $p_S = p^*$. The router's revenue is $R = \tau \cdot Q$, which covers the store and convert costs of the AFSC principle.

Unlike traditional grids where *Supply* = *Demand* must be instantaneous, the A-grid clears over a time interval $[t_1, t_2]$ using the *Energy Streaming Layer*.The market clears when the total energy demanded (at the higher price p_C) plus the change in the router's buffer equals the total energy supplied:

$$\sum_i q_i^D(p^* + \tau) = \sum_j s_j^S(p^*) - \Delta E_{buffer} \tag{4}$$

Where $\sum s_j^S(p^*)$ is the aggregate supply from prosumers and ΔE_{buffer} is the Store component of the AFSC principle and (p^*) the market clearing price. If there is an excess of supply, the router stores it ($\Delta E > 0$); if there is a deficit, the router releases it ($\Delta E < 0$).

In this model, the router charge τ creates a wedge between what consumers pay and prosumers receive. However, because the A-grid architecture provides Network Externalities $(\gamma \cdot N_{ext})$, the total utility U_i can still be higher than in a traditional grid.

In essence the Energy Router clears the market by solving a multi-period optimization that includes a buffer state. This optimization starts with a Social Welfare function(W)to be maximized:

$$\max W = \sum U_i - \sum C_j - C_{router} \tag{5}$$

Subject to the Asynchronous Energy Balance:

$$\int_t^{t+\Delta t} (P_{gen} - P_{load})dt + \Delta E_{buffer} = 0 \tag{6}$$

Where the prosumer j (e.g., a household with solar and battery) cost is the opportunity cost of not storing energy:

$$C_j(s_j) = c_j(s_j) + \Phi(B_j) \tag{7}$$

With s_j is the supply of energy stream, and $\Phi(B_j)$ is the battery degradation and storage cost.

If the local buffer is full, p^* drops to encourage consumption; if the buffer is empty, p^* rises to trigger the Forward (F) mechanism to pull energy from neighboring A-grids. This is how the market clearing price (p^*) in (26) is established.

The simple model outlined highlights the differences between a platform-based electricity market and the traditional market. First, prices vary by priority (QoS) rather than just time of day. Second, the energy router charges a matching fee for connecting buyers and sellers, similar to an App Store, instead of marginal cost pricing. Third, risk is moved from the global grid system, to the platform's storage capacity.

A final comment points to a potential challenge arising when the energy router (LMO) acts as a platform provider, charging a unit fee (τ). The challenge is that the energy router should not be allowed to exert platform monopoly power.

4.2 Dynamic Pricing and Demand Response

Within an A-grid, the price is not a fixed utility rate but a *Dynamic Price Signal* ($p_t(\theta)$) that reflects the current state of the local energy buffer (storage) and the "Forward" (F) availability from neighboring subgrids.

The Energy Router sets the price at time t based on the Action Energy (S) required to maintain the local subgrid's stability:

$$p_t(\theta_i) = p_{base} + \omega \cdot \left(\frac{1}{E_{buffer}(t)} \right) + \tau \tag{8}$$

Where p_{base} is the marginal cost of energy production, τ the router fee, and $\omega \cdot (1/E_{buffer})$ the scarcity premium. The later ensures that as the local router's buffer depletes, the price increases exponentially to discourage consumption.

Because the A-grid balances energy over an interval $[t_1, t_2]$ rather than at a single millisecond, it enables a "Store-and-Forward" behavior for appliances. A consumer's smart appliance (e.g., a dishwasher) acts as a follower in a Stackelberg Game, where the router is the leader. The consumer programs the appliance with a Flexibility Window (ΔT) and a Target Quality of Service (θ). The appliance then solves a cost-minimization problem:

$$\min \int_{t}^{t+\Delta T} p_t(\theta) \cdot q_t \, dt \tag{9}$$

Subject to:

$$\int q_t \, dt = E_{task} \tag{10}$$

Which is the total energy required to complete the cycle) and $t_{start} \in [t, t + \Delta T - T_{cycle}]$.

In a traditional grid, if a consumer turns on an appliance during a peak, they can contribute to a potential blackout or face a flat high rate. In the A-grid if p_t is high, the appliance waits. The router uses its Energy Streaming Layer to identify an upcoming surplus (e.g., a predicted wind surge in a neighboring A-grid). Once the price p_t drops below the consumer's threshold, the router pushes the energy stream to the appliance. This reduces the Peak-to-Average Ratio (PAR) of the subgrid - PAR is the ratio between the peak power demand (P_{peak}) and the average power demand (P_{avg}) over a specific time horizon (usually 24 hours). By reducing this, the energy router cab operate with smaller, cheaper buffers - and these savings can be passed on to the consumer.

The Application Layer uses the "Forward" (F) mechanism to route these streams only when network traffic is low, similar to how the Internet schedules large file downloads during off-peak hours. Because these appliances are programmed to respond to the price - which is itself a proxy for the router's energy state - the demand response becomes an inherent part of the grid's stability mechanism. If a fault occurs, the price spikes instantly, and all waiting appliances remain off, preventing a cascade.

4.3 Quality-of-Service (QoS) Models

In the case of the traditional merit-order demand-supply model of energy markets, the staircase supply curve for energy is obtained by ranking energy generators (renewables, gas, nuclear, etc) purely by marginal cost (mc_j). In that case the market cleared at a single price p where $Supply(mc) = Demand$.

In the A-grid architecture proposed by Schwarz et al. (2026), electricity can be treated as a service with varying levels of reliability and availability. Image a consumer i who can choose a quantity q_i and a quality level $\theta_i \in [0, 1]$, where $\theta = 1$ is a 100% guarantee (e.g., for hospitals) and $\theta = 0.1$ is highly flexible (e.g., for EV charging).The utility function is:

$$U_i = v_i(q_i, \theta_i) - p(\theta_i) \cdot q_i + \gamma N_{ext} \tag{11}$$

Where γN_{ext} is the network externality, representing the value of grid stability provided by the A-grid's compartmentalization.

Note that here the price ($p(\theta_i)$ is a function of quality. Higher θ costs more.

To find the optimal demand for a specific service level θ_i, the first-order condition with respect to q_i:

$$\frac{\partial U_i}{\partial q_i} = \frac{\partial v_i(q_i, \theta_i)}{\partial q_i} - p(\theta_i) = 0 \tag{12}$$

Solving for q_i gives the individual demand function:$q_i^D = f(p(\theta_i), \theta_i)$.

Since energy routers act as the decoupling elements that manage energy streams between A-grids, the costs of AFSC (Aggregate, Forward, Store, Convert) needs to be covered, and this can be done through a router charge τ added to the clearing price.

The price perceived by the consumer on the application layer becomes the clearing price plus the router fee:$p_{consumer} = p(\theta_i) + \tau$.

Thus, the individual demand adjusted for the router charge is:

$$q_i^D(p(\theta_i) + \tau) \tag{13}$$

The Energy Streaming Layer coordinates the global energy balance by managing these streams over time rather than instantaneously. The total demand in the A-grid is the sum of all individual demands across all service levels:

$$\text{Total Demand} = \sum q_i^D(p(\theta_i) + \tau) \tag{14}$$

The market clears when this total demand is equal to the total supply from prosumers ($\sum s_j^S$), adjusted for the Energy Buffer (ΔE_{buffer}) managed by the router. This gives the final equilibrium equation

$$\sum q_i^D(p(\theta_i) + \tau) = \sum s_j^S(p(\theta_i)) \pm \Delta E_{buffer} \tag{15}$$

Where τ is the router charge that covers the cost of storage and conversion and ΔE_{buffer} the energy stored or released by the router to smooth the market.

The Energy Router clears the market by matching demand to supply across time intervals, rather than instantaneously, using the AFSC principle (Aggregate, Forward, Store, Convert).

This feature of the A-grid improves utility from and the efficiency of the energy grid since consumers with flexible needs (low θ_i) pay lower prices, while those requiring high reliability (high θ_i) can guarantee their supply, maximizing individual satisfaction. Moreover the router uses the buffer (ΔE_{buffer}) to smooth intermittencies and perform traffic engineering, maximizing the throughput of the physical infrastructure.

4.4 Peer-to-Peer Energy Trading

A fourth business-model opportunity is direct, peer-to-peer (P2P) trading among prosumers, replacing the traditional model in which households or firms buy exclusively from a distant utility.

In an A-grid, the Local Market Operator (LMO) hosts what is, in effect, a continuous double auction: a household with excess solar generation bids a sell price based on its battery state, while a household with a shortfall bids a buy price; a trade occurs whenever the buy bid meets or exceeds the sell bid, typically clearing near the midpoint — a price above the seller's feed-in tariff and below the buyer's retail rate, and hence a improvement for both parties relative to trading through the incumbent utility.

What makes such trades feasible within an A-grid, and not generally within a traditional grid, is the underlying physical architecture: local inverters and DC links are active, routing electricity and balancing local voltage in real time, where a traditional grid might simply block a trade between two households on different branches of a transformer because of voltage-rise concerns. Prosumer revenue from such trades can be written as quantity traded times the P2P clearing price, net of a small 'cell fee" paid to the LMO to maintain local infrastructure; because energy does not travel far, transmission losses are close to negligible.

Consider the following hypothetical example. House A (the Seller) has excess solar energy. Its smart energy router bids a Sell Price (P_{sell}) based on its battery state. House B (the Buyer) needs to run a washing machine and dryer. Its smart energy router bids a Buy Price (P_{buy}). A trade occurs whenever $P_{buy} \geq P_{sell}$. The clearing price P^* is usually the midpoint, which is a win-win: it is higher than what the seller would get from the utility (feed-in tariff) and lower than what the buyer would pay the utility (retail rate).

This example can be extended by considering two houses in an A-Grid cell at 2:00 PM. House A, with plenty of solar power generates 5 kW and use 1 kW, generating a surplus of 4 kW, which is also the maximum battery capacity. If House A sells to the "Big Grid," it only gets 5 cents/kWh.

House B, down the street in the neighborhood, has its solar panel covered by shade, and hence generates 0 kW. The house demands 3 kW, result in an energy deficit of 3 kW. Now, if House B buys from the "Big Grid," it costs 30 cents/kWh.

The A-grid level LMO sees these two bids. House A's Bid is: "Will sell 3 kW for at least 10 cents." House B's Bid is: "Will buy 3 kW for up to 25 cents. Hence, the AI clears the trade at 15 cents/kWh. House A makes 10 cents more per kWh than the feed-in tariff.House B saves 15 cents more per kWh than the retail price.

What makes this work in an A-Grid (and not a traditional grid) is how the physics is handled. In a traditional grid, if these two houses are on different branches of a transformer, the local utility might block the trade because of voltage rise issues. In an A-Grid, the local inverters and DC links are *Active*. They route the electricity and balance the local voltage in real-time.The

$$\text{Prosumer Revenue} = Q_{P2P} \cdot P_{P2P} - \text{Cell\_Fee}$$

The *Cell Fee* is a tiny fraction paid to the AI-LMO to maintain the local wires. Because the energy does not travel far, there are almost zero transmission losses.

So far the example was of two houses in the same neighborhood where one house had a surplus energy and the other a deficit. But what happens when every house in an A-Grid cell has a surplus - as what could for instance happen during a sunny summer Sunday?

In this case the LMO transitions from a Market Matchmaker to a Logistics Manager. The LMO follows a specific mathematical sequence to handle the surplus while maintaining local grid stability.

First, it directs the surplus to the Community Battery Energy Storage System (C-BESS). If the "State of Charge" (SoC), $SoC < 100\%$, it buys the energy at a low price to save it for the evening peak when prices will be higher. This soaks up the surplus locally, preventing any power from even hitting the external interconnector.

Second, if the local battery is full, the LMO looks at the Asynchronous DC Link to the "Big Grid" or a neighboring cell. It compares the local marginal cost ($MC \approx 0$) with the price in the neighboring zone ($P_{neighbor}$). If $P_{neighbor} > 0.01$ EUR, the LMO schedules an export. Because the link is DC, the LMO can control the flow (e.g., exactly 100.0 kW) to ensure it does not overload the neighbor.

Thirdly, if the interconnector is also congested or the external price is negative, the ALMO triggers *Flexible Loads* that are otherwise idle. For example it can send a signal to a local municipal water pump, an electrolyzer, or a community thermal storage tank (heating water).

Fourthly, if all sinks are full, the LMO must reduce supply. In the traditional grid, this is "all or nothing." In the A-Grid, it is surgical curtailment. The LMO can, depending on surplus, send a signal to every solar inverter: "Reduce output by 12%." This shifts the supply curve down to match the maximum possible demand/export.

5 A Decentralized Portfolio of Real Options

A SAFErGrid-type architecture can be seen as a decentralized portfolio of real options. Each Energy Router and local buffer (BESS) provides a time value that increases with market volatility. As electricity markets in Europe becomes more volatile — owing to higher renewable penetration and rising demand — the value of the flexibility offered by such buffers becomes an increasingly significant source of value, both to individual households and firms and to the wider power system.

Applying the real options perspective on power-supply balancing developed by Zweifel et al. (2017), this section sets out that argument in two parts: the option value of an individual buffer, and the effect of a decentralized portfolio of such options on the systematic risk of the power system as a whole.

5.1 The Value of the SAFErGrid Flexibility Option

For an Energy Router, the flexibility to store energy when prices are low (typically, when the grid is stable) and to discharge it when prices spike (typically, when the grid approaches its thermal limits) constitutes a real option: the right, but not the obligation, to take an action — here, discharging a buffer — at an effective strike price equal to the marginal cost of the next-best alternative for grid stabilization, such as redispatch or the purchase of balancing power on the wholesale market.

Formally, decentralized energy buffers can be modeled as call options on grid flexibility. Adapting the Black-Scholes framework as set out by Zweifel et al. (2017, p.59), the value of such a call option can be written

$$CALL_t(T) = p_t \cdot N(d_1) - e_T \cdot e^{-i \cdot (T-t)} \cdot N(d_2) \tag{16}$$

Where p_t is the current spot value of the underlying asset, which represents the present value of the expected contribution margins or the avoided costs of redispatch and balancing power; e_T the exercise price or strike price, which represents the annualized investment and maintenance cost (Inv_0) of the buffer and energy router; i is the risk-free interest rate; σ is the annualized volatility of the underlying value (the price of avoided redispatch), which is driven by the intermittency of renewable generation and fluctuations in demand. Finally, $T - t$ is the remaining operational lifetime or time to maturity of the router and buffer system.

The terms $N(d_1)$ and $N(d_2)$ represent the cumulative distribution function of the standard normal distribution, providing the probabilities that the option will end up in the money. The parameters d_1 and d_2 are according to Zweifel et al. (2017, p.59) calculated as:

$$d_1 = \frac{ln(\frac{p_t}{e_t}) + (i + \frac{\sigma^2}{2}) \cdot (T - t)}{\sigma \cdot \sqrt{T - t}} \tag{17}$$

and

$$d_2 = d_1 - \sigma \cdot \sqrt{T - t} \tag{18}$$

The total value of the SAFErGrid flexibility option ($CALL$) is the sum of its intrinsic value, and its time value.

The intrinsic value of the buffer represents the immediate profit that would be realized if the option were exercised at the current price levels. For a call option, this is:

$$IntrinsicValue = max(0, p_t - e_T) \tag{19}$$

In the legacy synchronous grid, the capacity utilized is capped at a stability factor ($\sigma \approx 0.6$ to 0.7) of the thermal limit $K_{thermal}$. In the SAFErGrid a-grid, high-speed energy routers use buffering (B) to shave peaks and manage RoCoF locally, allowing the system to operate safely at $K_{a-grid} = K_{thermal}$.

The intrinsic value of the buffer is thus equivalent to the present value of the reclaimed capacity of the transmission network. By allowing existing lines to carry 30-40% more energy, the buffer avoids the need for new grid expansion investments.

The time value (or extrinsic value) of the buffer is the difference between the total option price and the intrinsic value:

$$TimeValue = CALL_t(T) - max(0, p_t - e_T) \tag{20}$$

The time value reflects the potential for future volatility to push the scarcity premium, p_t, even higher.

As Zweifel et al. (2017) emphasize, time value is highest when the option is "at the money" — meaning when the expected contribution margin p_t is roughly equal to the annualized cost e_T. In this state, the decision to discharge or store energy is most critical. In a synchronous grid, households face a decoupling of price signals; the high costs of redispatch from a *Dunkelflaute* event are only added to grid fees in the following year, providing no incentive for real-time demand response. The SAFErGrid Energy Router, however, receives packet-priority signals based on the instantaneous power of *Action*. The time value of the buffer is thus the flexibility premium that allows the AI-Local Market Operator (LMO) to wait for the most severe price spikes before discharging.

A counter-intuitive insight from Zweifel et al. (2017) is that, unlike traditional investments where risk reduces value, the value of an option increases with volatility. This is because the option holder has limited downside risk (they only lose the investment e_T) but unlimited upside potential when prices spike. The sensitivity of the call value to changes in volatility (σ) is known as *Vega*, (ν) - see Zweifel et al. (2017, p.61):

$$Vega = \frac{\partial CALL}{\partial \sigma} \tag{21}$$

Applying the partial derivative to the Black-Scholes formula, *Vega* can be expressed as:

$$Vega = p_t \cdot \sqrt{T-t} \cdot \frac{1}{\sqrt{2\pi}} \cdot e^{-\frac{d_1^2}{2}} \tag{22}$$

As the share of renewable energy sources in Germany increases toward the 80% target for 2030, the volatility (σ) of net load (demand minus intermittent supply) will grow non-linearly.

In a legacy synchronous grid, this volatility is a catastrophic liability, leading to RoCoF events and expensive redispatch. However, for a SAFErGrid buffer, the positive Vega ensures that as volatility increases, the value of the flexibility provided by the router becomes significant. Every increase in σ shifts more probability to the “in-the-money” side of the payoff function, where the scarcity premium p_t is high.

5.2 Lowering the Systematic Risk of the Power System

Beyond raising the value of any individual flexibility investment, a decentralized portfolio of real options of this kind also lowers the systematic risk of the power system as a whole. In the

Capital Asset Pricing Model as set out by Zweifel et al. (2017, pp.50-53), the risk-adjusted required return on a project, ROI^*, is a function of the risk-free rate i and the project's systematic risk, or beta:

$$ROI^* = i + \beta \cdot (E(q_{market}) - i) \tag{23}$$

β is defined as the covariance between the project's return and the market return, normalized by the market's variance Zweifel et al. (2017, p.51):

$$\beta = \frac{COV(ROI_{project}, q_{market})}{\sigma^2_{market}} \tag{24}$$

In a synchronized AC grid, any major instability or fossil-fuel price shock (like the 2025 Iran war fossil fuel price shock) affects all industrial sectors simultaneously. This creates a high positive covariance between energy costs and market performance, leading to a $\beta \geq 1$. Investors demand a higher risk premium for such systems, which further inflates grid expansion costs and household bills.

SAFErGrid's value is obtained in this regard due to its decoupling effect. The energy routers and buffers in SAFErGrid lower β through several channels.

The first is that by decoupling A-grids from the global frequency, the routers act as financial and physical circuit breakers. Shocks in one region are managed by Action Energy within the subgrid's buffer, preventing the shock from propagating through the entire market. This reduces $COV(ROI_{grid}, q_{market})$.

The second is that traditional grids are OPEX-heavy due to redispatch fuel costs. Renewables have near-zero marginal costs, meaning the cost of the system shifts toward CAPEX (infrastructure). Operating costs for SAFErGrid are largely risk-less over time, because they are driven by semiconductors and buffers rather than volatile fossil fuels.

The third is that the SAFErGrid router earns its highest contribution margins during periods of extreme grid stress -exactly when the rest of the economy experiences energy scarcity. In this case, $\beta < 0$, and the SAFErGrid flexibility option acts as an insurance policy that stabilizes the total market.

6 Concluding Remarks

The perspectives developed in this paper suggest that the economic case for a decentralized, asynchronous architecture such as SAFErGrid extends well beyond its ability to resolve balancing, inertia, and congestion problems in the conventional synchronous grid. Three distinct but related contributions to innovation economics and strategy follow from considering decentralization in this way.

The first is that compartmentalizing the grid into autonomous A-grids, connected by store-and-forward Energy Routers and governed by new stability concepts such as Action Energy, constitutes a genuine technology and innovation agenda in its own right — one with its own research and development requirements in hardware, protocols, and metrology, distinct from, though complementary to, the engineering case for adopting the architecture.

The second is that separating a physical routing layer from a software-defined application layer effectively creates a platform. Much as multi-sided digital platforms enabled waves of downstream innovation once shared infrastructure was in place, a smart Energy Router acting as a multi-sided platform provider can support dynamic pricing, quality-of-service contracting, and continuous peer-to-peer trading between neighbors — sustaining itself through a modest routing fee on transactions, analogous to an app-store commission, rather than through marginal-cost utility pricing, while saving prosumers the transmission losses and markups associated with a distant utility. As in the case of other platform markets one may expect that these functions enabled via die Energy Router will raises governance questions - for instance how to prevent the platform provider (the Local Market Operator) from exercising monopoly power over the ecosystem it hosts.

The third, contribution is to see decentralized energy infrastructure as a portfolio of real options. Because the value of an option rises with volatility rather than falling with it, a grid built from many distributed flexibility options is suited to an environment of increasing renewable intermittency. The feature that threatens the traditional synchronous grid becomes in essence a source of increasing option value.

Taken together, these three perspectives — technological innovation, platform-enabled business models, and a portfolio of real options — imply that decentralization of the kind proposed in SAFErGrid does more than help address the challenges of managing a grid facing increased RES penetration - it also constitutes a source of innovation.

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