ABSTRACT

The electricity sector of the European Union has entered a phase of persistent dispatchable power deficit. The accelerated decommissioning of coal-fired power plants and some gas units, the slow pace of constructing new nuclear units, and the increasing share of variable generation have led to a growing gap between formally installed capacity and capacity actually available during peak demand hours. Internal solutions—new nuclear power plants, hydropower, gas turbines, energy storage, and further expansion of renewable energy sources—are unable to eliminate this deficit within the next 10 years due to long implementation cycles, regulatory constraints, and high capital intensity.

Under these conditions, the article argues that the only realistic external source of cheap, dispatchable baseload power for the EU remains Ukraine. Unlike Russia and Belarus, which are excluded for institutional and systemic reasons, Ukraine combines a physical surplus of nuclear generation with technical and regulatory compatibility with ENTSO-E. The structural decline in industrial demand, combined with the preservation of the post-Soviet nuclear power plant fleet, creates a persistent export resource that cannot be realized through existing alternating current interconnections due to network constraints and risks of synchronous operation.

The article proposes a solution in the form of an asynchronous HVDC back-to-back interconnection with a capacity of 2 GW, expandable in stages to 4 GW, located on Polish territory. It is demonstrated that this technology is industrially mature, widely used worldwide, and feasible within 2–3 years. Total investment costs are estimated at 1–1.2 billion EUR, which is an order of magnitude lower than alternative methods of creating a comparable volume of dispatchable power. Based on observed price differentiation between the Ukrainian market and Central European markets, the project's payback period is estimated to range from less than one year in favorable scenarios to 3–5 years in stress scenarios, with a baseline value of around 2–3 years.

Particular attention is devoted to the institutional structure of the Ukrainian energy market. An analytically neutral concept of the "Ukrainian side" is introduced as a persistent configuration of economic interests determining the sector's behavior. It is shown that nuclear energy exports are not a temporary political choice but a structurally conditioned mechanism for rent extraction and an internal actor selection factor, making export flows predictable even under high political and military uncertainty.

A scenario analysis was conducted, covering Ukraine's economic stagnation, transfer of nuclear power plants to Western companies, formal or de facto abandonment of the EU's green agenda, deterioration of the military-political situation, and even partial or complete change in territorial control. In all realistic scenarios, available export capacity is preserved or increased; the only formally unfavorable scenario—rapid economic reconstruction of Ukraine—has a probability below 1% and does not affect the project's investment assessment.

Separately, it is justified that locating the HVDC interconnection in Poland creates a natural infrastructure monopoly. EU regulatory practice does not permit duplication of large inter-zonal introductions after closing the power deficit, making the first implemented project dominant for decades. Thus, the HVDC back-to-back interconnection between Ukraine and Poland should be viewed not as an energy project but as an infrastructure project generating persistent export rent, comparable in significance to Europe's largest ports and transit hubs.

The article concludes that constructing an HVDC back-to-back interconnection in Poland represents the dominant solution for rapidly eliminating the dispatchable power deficit in Central Europe within a 10-year horizon, while providing the European Union with access to cheap baseload generation and Poland with a long-term economic and institutional role as a key energy hub.

CHAPTER 1. Introduction: Dispatchable Power Deficit in the EU

The European Union's electricity system has entered a period of structural dispatchable power deficit. Formally installed capacity is growing, mainly due to solar and wind power plants, but actually available capacity during hours of minimal insolation and weak wind is decreasing. This is not a short-term imbalance but the result of overlapping long-term processes, whose reversal within the next few years is impossible.

Before proceeding to a detailed analysis of these processes, it is necessary to define the methodological framework of the study. The analysis of the dispatchable power deficit cannot be limited solely to technical or physical parameters of the electricity system. The electricity sector functions as an element of the economic system and remains inextricably linked to financial markets, industrial demand structure, regulatory environment, and political decisions. In real conditions, it is precisely the combination of technical, economic, and institutional factors that determines which energy solutions are feasible and which remain theoretically viable but practically unimplementable. Therefore, in this article, these aspects are considered together, without attempts to artificially separate "pure technology" from economics and politics.

Additionally, a limited time horizon for the analysis has been introduced. All conclusions and scenarios are considered within a 5–15 year range, corresponding to the real forecasting horizon for energy markets, investment decisions, and the political-economic environment. Long-term forecasts, under high uncertainty related to changes in climate policy, geopolitical configurations, and technological trajectories, have been deliberately excluded from the scope of this study.

The structural dispatchable power deficit in the EU is shaped by several factors. First, the accelerated closure of coal-fired power plants and part of gas generation under pressure from climate policy and emission allowance prices limits the share of synchronous sources that provide inertia and basic system services: frequency maintenance, primary and secondary reserves, and voltage regulation. Second, the construction of new nuclear units in Europe proceeds extremely slowly: implementation timelines exceed ten years, and actual delays make nuclear energy strategically important but unavailable as a short-term solution. Third, Europe's hydropower potential is practically exhausted: large dams have already been built, and new projects of significant scale are blocked by environmental and spatial constraints.

Fourth, the increasing share of variable generation intensifies seasonal and diurnal price variability. The availability of cheap energy in specific hours does not compensate for the shortage of guaranteed power needed to cover evening and winter peak demands. Fifth, European electricity systems are overloaded with internal transit flows (loop flows): surpluses in one region cannot be efficiently delivered to another due to inter-zonal connection constraints, making energy availability highly dependent on geography.

ENTSO-E, in its annual power adequacy reports, consistently indicates that without the emergence of new dispatchable generation sources or equivalent imports, several EU regions, including Central Europe, will experience reserve deficits and increasing risks of supply-demand mismatch during winter peaks. At the same time, there is a lack of quick solutions within the EU: new nuclear power plants cannot be built within the required timelines; gas turbines face high fuel prices and climate constraints; energy storage does not create power but only shifts it in time; grid reinforcement redistributes existing resources but does not increase their total volume.

As a result, the EU finds itself in a situation where internal instruments are unavailable within the critical time horizon, and the demand for dispatchable baseload power will grow with the increasing share of RES and further decommissioning of synchronous sources. Hence arises the key question: does an external source of cheap, stable, and emission-free power exist that can be connected to the European system sufficiently quickly and without increasing system risks?

CHAPTER 2. The Eastern Direction as a Potential Power Source

Europe's eastern peripheral energy area encompasses three countries with a large inherited Soviet-era fleet of nuclear and thermal generation: Russia, Belarus, and Ukraine. At first glance, this region could be perceived as an external source of dispatchable power for the EU, especially considering that constructing equivalent volumes of nuclear generation within the European Union by 2035 is practically impossible. However, the technical, institutional, and political parameters of these countries differ fundamentally, and only one can be considered a realistic partner for electricity exports.

Russia and Belarus are excluded first for institutional reasons. The European Union has introduced direct restrictions on electricity imports from Russia and Belarus, and these restrictions are not dependent on the current state of the EU's electricity system. Even in a hypothetical scenario of political configuration change, fundamental systemic barriers remain. The lines connecting Belarus to Poland and the Baltic states were not designed for 1–2 GW westward transmission; their capacity is limited, and increasing flows poses stability risks in both the IPS/UPS system and ENTSO-E.

Furthermore, Russia and Belarus operate within the synchronous IPS/UPS zone, entirely asynchronous relative to ENTSO-E. Connecting large flows between these zones is possible only through HVDC back-to-back stations. Such stations on the western borders of Russia and Belarus do not exist, and their construction in the current institutional configuration is impossible. Even with formal lifting of restrictions, European system operators will not accept risks associated with basing reserves on countries whose electricity system management strategies are not subject to ENTSO-E principles.

Also important is the broader institutional-economic context. Classical literature in political economy and game theory describes the difference between systems where elites derive rent from growth and profits, and systems where rent comes from stagnation and losses. In the latter case, a persistent degradation trajectory forms, akin to a negative-sum game, where total production decreases, but redistribution mechanisms are preserved, making escape from the decline trajectory endogenously difficult.

For the energy sector, this has direct consequences. In Russia and Belarus, the long-term rate of industrial demand changes is approximately comparable to the rate of modernization and depletion of inherited generation capacities, including nuclear energy. As a result, no persistent and growing gap arises between potential electricity production and domestic consumption: surpluses are episodic and do not form a basis for long-term dispatchable power exports.

In Ukraine's case, a different dynamic is observed. The decline in industrial production and domestic electricity consumption over the last decades has occurred faster than the degradation and decommissioning of the post-Soviet nuclear power plant fleet. As a result, the gap between potential nuclear generation production and domestic demand is not cyclical but structural and shows a tendency to deepen. From the perspective of institutional economics, this trajectory is stable: with existing incentives maintained, the system reproduces a generation surplus that the internal market cannot absorb, which consequently requires an external monetization channel.

Against this backdrop, Ukraine remains the only eastern source that combines significant emission-free generation with technical and regulatory compatibility with the EU. The partial synchronization of Ukraine's electricity system with ENTSO-E in 2022, despite its emergency nature and strict limitations, confirmed technological and normative compliance. At the same time, existing transmission lines can transmit only hundreds of megawatts, making realization of export potential impossible without creating a large-capacity asynchronous interconnection.

Thus, if the EU needs an external source of dispatchable baseload power by 2030, the choice is essentially binary: either Ukraine or no such supplies at all.

CHAPTER 3. Structural Features of the Ukrainian Electricity System

Ukraine's electricity system represents a rare example in Europe of combining a long-term structural decline in electricity consumption with the preservation of a significant fleet of baseload nuclear generation. In 1990, electricity production exceeded 290 TWh; by 2014, this indicator had decreased by nearly half, and after 2022—even further. At the same time, the demand decline occurred faster than the loss of generation capacities: deindustrialization in the eastern and southeastern regions led to a reduction in baseload, while nuclear power plants, located in the western part of the country and built during the Soviet period, retained significant physical resources. Taking into account extensions of operating periods, the operating units can provide 12–14 GW of installed capacity over a horizon of at least 25–30 years. This gap between the structural demand decline and the inertial nature of baseload generation decommissioning creates a persistent and long-term export potential for the electricity system.

It is fundamentally important to emphasize that the Ukrainian electricity system does not function as a market in the classical European sense. Despite the formal existence of prices, tariffs, and settlements, the actual logic of the sector's operation is closer to what was termed a supplier system in the Soviet period. Therefore, the numerical data cited in the further part of the text (production volumes, exports, price levels, and their dynamics) should not be interpreted as market signals in the strict sense. They describe physical flows and accounting parameters but do not reflect the actual structure of incentives or decision-making mechanisms in the sector.

In the Ukrainian energy sector, the key factor is not supply-demand balance but rent extraction from existing generation infrastructure. The system is therefore neither "export-oriented" nor "import-oriented" by nature and does not permanently orient toward high or low price levels. It adopts a configuration—internal or external, with high or low prices—that at a given moment provides the most stable and controllable rent for key actors. Consequently, the numerical values presented further should be treated not as a forecast of market behavior but as an illustration of the system's scale and physical potential. In the presence of a technically and institutionally secured export channel, such as an HVDC interconnection on the Polish side, Ukrainian electricity shifts structurally and persistently into export mode, independent of current domestic prices, demand status, or social burdens.

Nuclear generation occupies a central place in Ukraine's energy balance and possesses a specific institutional feature that fundamentally distinguishes it from most other sectors of the economy. The economic value of nuclear energy is realized solely in the process of exploiting generation capacities. Unlike industry, where privatization, asset sales, equipment dismantling, or disposal of production sites are possible for one-time rent extraction, nuclear energy does not allow such forms of value conversion. A reactor shut down for an extended period generates no income, and nuclear power plant infrastructure cannot be efficiently transformed into alternative assets. Thus, the nuclear sector is structurally deprived of "value extraction" mechanisms beyond the production process.

This circumstance determines the sector's relatively low susceptibility to corruption compared to other segments of the Ukrainian economy. Despite periodic public scandals related to individual contracts or management decisions, nuclear energy—and particularly the power plant operator—in practice remains one of the most institutionally stable and least degraded branches of the economy. In contrast to, for example, the aviation industry, where rent can be obtained through sales of aircraft, equipment, production halls, or land, nuclear energy preserves its value solely in the mode of continuous block operation. An additional stabilizing factor is the constant international oversight by the IAEA, which significantly limits the arbitrariness of management decisions and narrows the field for informal practices.

At the same time, Ukraine's nuclear sector is characterized by deep and multilayered structural linkage with Russia, shaped during the Soviet period. This dependence is not only institutional or personnel-related but also has an objective technological basis. Ukrainian nuclear power plants were designed within a single Soviet engineering school; a significant portion of design documentation, calculation methods, technological regulations, and design solutions was historically concentrated in Russian organizations. Similarly shaped were the supply chains for key components: fuel, spare parts, specialized equipment, and operation support services. Even under political rupture, this technological inertia continues to impact the sector's functioning.

It should be emphasized that this type of dependence is not unique to Ukraine. A characteristic example is the fact that even the United States imported Russian nuclear fuel or raw materials for its production for a long time, underscoring the global nature of the shaped technological chains. Thus, the linkage of Ukrainian nuclear energy with Russia encompasses both elements related to informal economic practices and export-import operations, as well as objective engineering-technological constraints impossible to remove in the short term.

A separate analysis is required for the institutional environment in which the Ukrainian energy market operates. In this article, the analytically neutral concept of the "Ukrainian side" is used, denoting a persistent configuration of economic interests influencing key decision-making in the energy sector. The personal and political composition of this group is variable: the same participant may hold positions in state administration bodies, thermal generation sector, renewable energy segment, or structures related to electricity sales and distribution at different times. However, despite all external variability of roles, the internal logic of this group remains stable.

It is fundamentally important that this configuration of interests does not have a monolithic character. Within it, there is constant competition for control over financial streams and access to the most stable rent sources. Under these conditions, the existence of a reliable export channel for nuclear generation acquires significance not only as a preferred direction of activity but as an internal selection mechanism. Actors capable of ensuring and maintaining electricity exports to the EU gain a structural advantage; those who, for various reasons, hinder supplies or reduce their reliability will inevitably lose positions and be displaced by competitors within the group itself. In this way, exports become not only a persistent interest but also a selection factor.

A key feature of the Ukrainian electricity system under these conditions is its behavioral predictability. In various periods, nuclear power plants were switched to reduced operating modes, freeing market space for more expensive thermal generation. Regardless of normative assessments, this practice reflects the persistent structural logic of the system, in which electricity exports constitute a more stable, less politically sensitive, and institutionally secured source of income than domestic supplies. In the presence of a reliable, technologically controlled, and asynchronous energy transmission channel to the EU, these incentives will not weaken but strengthen.

Thus, the Ukrainian electricity system possesses a set of features distinguishing it from potential suppliers of dispatchable baseload power: a long-term maintained surplus of nuclear generation, deeply rooted institutional and technological inertia, and persistent orientation of key economic actors toward exports. In contrast to Russia and Belarus, Ukraine is technically and regulatorily compatible with ENTSO-E; in contrast to most EU countries, it has a preserved baseload generation fleet with an operating horizon of several decades. These structural properties create an objective premise for constructing a large-capacity asynchronous interconnection intended to realize the export potential of Ukrainian electricity.

CHAPTER 4. Possible Directions for Strengthening the "Ukraine–EU" Interconnection

Existing inter-system interconnections between Ukraine and EU countries were shaped within Soviet and post-Soviet network topology and were never designed for transit of dispatchable power in volumes of 1–4 GW westward. The four main directions—Hungarian, Slovak, Romanian, and Polish—are characterized by fundamentally different technical parameters, but all, except the Polish direction, encounter constraints making them unsuitable for realizing large asynchronous imports to Europe.

Hungary. The Hungarian direction was historically used as an element of the interconnection between the Ukrainian and Hungarian 750 kV system, but the contemporary Hungarian network cannot accept additional flow on a scale exceeding a few hundred megawatts. After 2022, Hungary oriented its energy policy southward (Serbia, Balkans) and toward internal gas sources. Strengthening the "Mukachevo–Albertirsa" line would require a deep reconstruction of the entire Hungarian 400 kV network configuration. Even with full political agreement, Hungary lacks free network reserves allowing import scaling to 2 GW, and the necessity of operating within the synchronous Continental Europe zone excludes using this direction as an asynchronous gateway.

Slovakia. The Slovak direction is technically closest to Ukrainian nuclear generation but is limited by its own network geography and load level. The Slovak 400 kV network operates near its transit capacity limits: a significant portion of flows is realized along the north-south axis toward the Czech Republic and Austria. Attempting to add another 1–2 GW from Ukraine would require extensive reconstruction of internal nodes and introduction of additional safety constraints, making the project economically ineffective. Furthermore, any increase in transit through Slovakia would generate increasing pressure on the Czech system, where loop flow risks are already identified. As a result, Slovakia can handle only point export operations but is unsuitable for constructing a large asynchronous energy bridge.

Romania. The Romanian network formally has access to strong nodes, including the Cernavodă nuclear power plant, but connections with Ukraine are among the weakest of all four directions. Eastern Romania is a net energy-importing area, while southern and western lines are loaded with transit toward the Balkans. Ukraine can physically transmit only small power volumes to Romania, and scaling them to 1–2 GW would require building entirely new infrastructure on both Ukrainian and Romanian sides. Further transit of this power through Romania to Central Europe is impossible due to the lack of appropriate network reserves.

Poland. The Polish direction is the only one where creating a large asynchronous interconnection is possible without reconstructing the EU's national network. The "Khmelnytskyi–Rzeszów" line (750/400 kV), built during the Soviet period, enables physical delivery of 2–4 GW of power to the Polish side under the condition of installing a back-to-back converter on Polish territory. Unlike Hungary, Slovakia, and Romania, the internal configuration of the Polish 400 kV network has sufficient depth and reserves to accept such a power volume provided a back-to-back converter is installed.

Thus, among all potential directions for strengthening the "Ukraine–EU" interconnection, only the Polish direction combines the physical possibility of 2–4 GW transmission, absence of critical transit overloads, and institutional compatibility with ENTSO-E principles. The other directions are limited by network topology, lack of reserves, or the necessity of incurring significant infrastructure investments on the side of third countries. Poland thus remains the only EU country where constructing a large-capacity asynchronous interconnection can be realized in a short time and without changing the baseline configuration of the European electricity system.

CHAPTER 5. Technological Models for Increasing Transmission Capacity

Increasing transmission capacities between Ukraine and the EU can be realized in five technological configurations: strengthening existing alternating current lines, building new AC lines, realizing HVDC connections without galvanic separation, installing back-to-back stations on Ukrainian territory, and locating such a station on Polish territory. Despite apparent technological diversity, all variants except the last encounter fundamental constraints making them unsuitable for power transmission on a 2–4 GW scale.

Strengthening existing AC lines. Alternating current transmission between Ukraine and the EU is limited both by the lines' own capacity and the stability of systems operating in different regimes. The Ukrainian network is characterized by high frequency variability and weakness of western nodes, especially under infrastructure damage during hostilities. Increasing flows on existing AC connections leads to heightened risks of cascading outages, which has been repeatedly noted by system operators. Even theoretically strengthened lines cannot ensure 2 GW exports without threatening frequency stability on both sides of the synchronized blocks. In practice, this variant should be considered technically and operationally infeasible.

Building new AC lines. Designing a new alternating current line between Ukraine and the EU requires synchronous operation of the electricity systems. This means ENTSO-E assuming obligations for maintaining Ukrainian system frequency or—alternatively—full adaptation of Ukraine to European stability standards. In real conditions, neither of these can be met in the short term. Furthermore, even if a new AC line is built, its actual capacity would be limited by internal EU nodes, which are already overloaded with north-south and east-west transits. A scalable export model in AC configuration does not exist.

HVDC without separation (monopolar or bipolar lines). This variant theoretically enables power transmission between asynchronous zones without synchronization but requires building complete HVDC infrastructure along the entire route—from the Ukrainian node to the EU reception point. In European conditions, this means realizing a new HVDC line 200–400 km long, involving multi-year planning, land acquisition, environmental approvals, and investments in the billions of euros. Implementation timelines for such projects in Europe are 7–10 years, excluding this variant as a quick tool for increasing transmission capacities.

Back-to-back station on Ukrainian territory. Locating a back-to-back converter station on Ukraine is technically possible but institutionally and investment-wise burdened with high risk. Such an object inevitably becomes incorporated into the system of internal conflicts and competing interests, becoming a tool for redistributing export rent. Ukrainian energy market practice shows that access to infrastructure of this scale can be used as a pressure instrument—through limitations on power issuance, changes in operating regimes, or selective outages. Under these conditions, European operators and investors cannot treat such an object as a credible asset, as its functioning depends not on technical parameters but on political decisions.

Global energy market experiences show that trade in energy is possible even with corrupt, authoritarian, or institutionally weak regimes, provided they do not possess direct instruments to impact the end recipient. Even limited export rent is acceptable for the supplier in such cases. However, transferring control over critical infrastructure fundamentally changes the balance: the possibility of halting or limiting supplies becomes a blackmail tool, regardless of formal contracts or declarations.

Locating a back-to-back station on the Ukrainian side creates precisely such an instrument. In conflict conditions, institutional risks are compounded by high physical vulnerability of the node object. Collectively, this makes building a converter station on Ukrainian territory strategically unacceptable, despite its formal technical feasibility.

Back-to-back station on Polish territory. Locating the converter station in Poland eliminates key risks and simultaneously ensures technical controllability of flows. The Polish 400 kV network has sufficient depth and stability reserves to accept 2–4 GW without radical topology reconstruction, and the Polish system operator can ensure compliance with European requirements for frequency stability and reserves. Investments are protected by European legal order, and the object itself becomes part of the EU's critical infrastructure. At the same time, incentives remain on the Ukrainian side for maximizing nuclear generation utilization: export rent remains higher than the domestic tariff, while "valve" control on the Polish side eliminates blackmail risks and makes export flows predictable.

Thus, among the five technological models, only one—HVDC back-to-back on Polish territory—combines scalability (2–4 GW), technical stability, institutional predictability, and feasibility within a 2–3 year horizon. All others are limited physically, operationally, or institutionally. This justifies proceeding to analyze the specific architecture and economic model of the project.

CHAPTER 6. Project Architecture for HVDC Back-to-Back in Poland

Creating an asynchronous interconnection between Ukraine and the European Union requires an architecture that simultaneously meets three criteria: technical scalability to 4 GW, institutional stability, and accelerated implementation within a 2–3 year horizon. Practically the only configuration meeting these conditions is locating an HVDC back-to-back station on Polish territory, with connection to existing 400 kV network nodes and power delivery via the "Khmelnytskyi–Rzeszów" line.

It should be emphasized that HVDC back-to-back technology is not experimental or innovative. Dozens of such stations are operated in various regions worldwide as interfaces between asynchronous electricity systems or zones with different market and regulatory regimes. Classic examples include back-to-back stations in the United States (between ERCOT and the rest of the North American system), in Scandinavia (between Norway, Sweden, and continental Europe), in Japan (between networks with different frequencies), as well as in China and India. Typical capacities of such objects range from a few hundred megawatts to 2–3 GW, making a 4 GW scale technically realistic with modular implementation. The proposed configuration is thus based on mature and repeatedly verified engineering practice.

The technical basis of the project stems from the fact that the 750/400 kV line, built during the Soviet period, can physically carry a power stream up to 4 GW provided appropriate converter equipment is installed. The line itself cannot operate synchronously with ENTSO-E but serves as a ready transmission corridor enabling power delivery to the Polish side, where the converter station is located. The Polish 400 kV network has sufficient depth and reserves to accept an import of this scale: flow redistribution can be realized through central and northern nodes without violating N-1 reliability criteria and without needing new autotransformer substations.

The project architecture assumes staged implementation: a first phase of 2 GW, followed by expansion to 4 GW. This approach limits initial investment risk and enables commercial operation of the object after the first stage's completion. The first phase cost is estimated at 700 million – 1 billion EUR, the second at 300–500 million EUR, totaling 1–1.2 billion EUR. Infrastructure includes land near existing 400 kV nodes (e.g., in the Rzeszów area or a comparable node with capacity reserves), its own substation, converter modules, DC busbars, cooling systems, harmonic filtration, protections, and automated control systems fully compliant with ENTSO-E requirements.

The fundamental significance of this architecture is not limited to technical parameters but concerns its systemic role. The asynchronous interconnection serves as a "bottleneck"—a controlled infrastructure interface through which energy flows regardless of changes in political regimes, economic models, or generation structure on both sides of the border. Historical experience shows that such nodes accumulate persistent infrastructure rent. For centuries, exports of agricultural products from Polish lands passed through Gdańsk, regardless of changes in states, borders, and ruling elites, with the essential portion of benefits captured by those controlling the trade node. Similarly, Germany's foreign trade—from empire through republic to contemporary state—passed through northwestern ports, including Antwerp and Rotterdam, ensuring stable rent for the respective infrastructure. A classic global example is the Suez Canal, through which world trade has flowed for decades regardless of the region's political dynamics.

In this context, the HVDC back-to-back interconnection serves an analogous function in electricity. Regardless of what generation dominates in Ukraine, what governments form, or what changes occur in EU energy policy, the controlled asynchronous interface remains a functional and economically significant element of the system. Hence, the institutional location of the station in Poland is a key element of the project architecture. Placing the converter infrastructure under EU jurisdiction eliminates the possibility of using the object as a pressure tool, covers the investment with European legal protection, and makes the interconnection part of the Union's critical infrastructure.

The implementation timeline is determined primarily by administrative and regulatory procedures. Key HVDC equipment is produced serially and can be delivered within 12–18 months; construction works and tests require another 8–12 months. With political decision and granting the project priority status, completion is possible within 2–3 years, which is a timeframe significantly shorter than for any alternative sources of dispatchable power of comparable scale, including new gas power plants, hydropower facilities, or nuclear blocks.

Thus, the HVDC back-to-back architecture in Poland represents a standardized, institutionally secured, and strategically durable solution, enabling transformation of the asynchronous interconnection into a long-term infrastructure asset. The project can provide the European Union with up to 4 GW of external dispatchable power without radical network reconstruction and without increasing system risks, making it a unique solution in terms of combining speed of implementation, scale, and stability.

Why is an HVDC back-to-back station needed if the electricity systems of Ukraine and continental Europe have already been synchronized since March 2022 and formally operate in a single ENTSO-E frequency zone?

The answer lies in the fundamental difference between synchronous and asynchronous interconnection. In synchronous AC mode, the two power systems become electrically one. This means that frequency must be strictly identical on both sides of the border. Any major disturbance—sudden unit trip, infrastructure attack or significant imbalance in Ukraine—immediately propagates to the Polish and further European network. The Ukrainian power system under current conditions is characterized by significantly lower inertia and higher frequency variability compared to Continental Europe (as confirmed by 2026 data: import capacity has grown to 2,450 MW, but export along the Polish direction remains strictly limited precisely due to stability risks). Therefore, transmitting power in volumes of 2–4 GW along existing lines creates unacceptable risks of cascading outages for the whole of Europe.

The HVDC back-to-back station solves this problem radically. It operates as a controlled “electrical gateway”: it transmits active power but completely separates the two systems in terms of frequency, reactive power and inertia. This allows safe import of up to 4 GW of dispatchable capacity without threatening European network stability and gives the Polish operator full control over the flow (“valve”). This is exactly why all alternative options for strengthening existing AC connections turn out to be either technically limited or unacceptably risky.

CHAPTER 7. Economic Model of the Project

The economic efficiency of the HVDC back-to-back project is determined by the margin between the cost of electricity acquired on the Ukrainian side and its selling price on the EU wholesale market. This model is not unique: large inter-zonal interconnections in North America, Scandinavia, and the Middle East operate similarly. However, in the EU–Ukraine context, the scale of price differences and the structural dispatchable power deficit in the EU generate above-normal rent.

Revenue Structure

Export power of 2 GW at an average annual utilization of 70–80% corresponds to a volume of 12–14 TWh annually. Even with conservative price differentiation of 40–60 EUR/MWh, gross annual revenue is 0.5–0.8 billion EUR. After expansion to 4 GW—respectively 1–1.6 billion EUR. These estimates are based on observed differences between Ukrainian wholesale prices, limited by low paying demand and high share of amortized baseload, and wholesale prices in Central Europe, where chronic dispatchable power deficit persists.

In addition to the baseline price difference, the project generates additional revenue streams through price arbitrage between hourly and daily market segments, capturing peak premiums during EU power deficits, participation in balancing markets, and provision of system services (ancillary services). An additional income source is infrastructure rent arising from control over the nodal DC interface.

Cost Base of the Model

Over the last 10 years, average wholesale prices in Central European countries have ranged from 50–150 EUR/MWh, with regular peaks exceeding 200–300 EUR/MWh during deficits. Ukrainian prices remain systemically lower due to industrial demand decline, high share of amortized nuclear generation, and presence of a regulated market segment.

Analysis of averaged data over a longer horizon (up to 2022) shows that average prices in Central Europe were mainly in the 60–90 EUR/MWh range, while Ukrainian prices were around 20–40 EUR/MWh. This creates a persistent price differentiation of 40–70 EUR/MWh, which is not a consequence of individual crisis years. The indicated structural factors are inertial and will not change in the nearest decades: nuclear power plants amortize slowly, and reconstruction of industrial demand in Ukraine remains limited.

Rent Division Between Sides

For project stability, ensuring economic motivation on the Ukrainian side is necessary. Export rent is divided into three circuits: covering transmission and maintenance costs, profit of the HVDC operator on the Polish side, and income of the Ukrainian side, stimulating exports and nuclear generation loading. The rent share allocated to the Ukrainian side eliminates incentives for limiting supplies and makes exports more profitable than domestic sales even under internal energy deficit conditions, which has been repeatedly observed on the Ukrainian market.

Investments and Capital Expenditure Structure

The first project stage (2 GW) is estimated at 700 million – 1 billion EUR and includes construction of the converter station, modernization of the 400 kV node, and connection infrastructure. The second stage (expansion to 4 GW) requires 300–500 million EUR. Average total project cost is 1–1.2 billion EUR. The project allows financing by Polish state or private companies, a consortium of European transmission system operators, and infrastructure funds, as well as going public (IPO) on the GPW or LSE.

Even in an IPO case, Poland can retain a controlling stake (at least 51%), treating the object as a strategic infrastructure asset. For infrastructure projects in energy, characterized by stable cash flows, stock market multipliers typically exceed capital expenditures 2–4 times, corresponding to potential capitalization of 3–5 billion EUR at a construction cost of about 1.2 billion EUR. In such a scenario, the project can be formally repaid already at the stock market debut, and further operation generates net income.

Payback Period and Sensitivity

With a conservative margin of 40 EUR/MWh and power utilization at 70%, the project reaches break-even in 2–3 years. With high power prices in Central Europe or significant peak differences, the payback period can be less than one year. Even in stress scenarios (price decline in the EU, partial underutilization), the payback remains within 3–5 years, which is a significantly better result than for alternative energy investments of comparable scale.

Macroeconomic Effect

For Poland, the project generates a persistent financial stream comparable to operating a large LNG terminal or gas hub. Control over the interface between markets transforms the host country into the owner of a key energy node through which the export stream is concentrated. EU regulatory practice does not permit arbitrary duplication of large inter-zonal introductions; after launching the first object, further capacity increases are realized through its modular expansion. This grants the project not only an economic dimension but also long-term political-economic significance.

Thus, the economic model shows that the HVDC back-to-back project is highly profitable, resilient to market shocks, and capable of payback in a shorter time than most European energy projects. The export rent arising on the controlled interface transforms the object into a source of long-term infrastructure profitability.

CHAPTER 8. Scenario Analysis and Institutional Resilience of the Project

The economic viability of the HVDC back-to-back interconnection is determined not only by price rent but also by resilience to political and institutional changes on Ukrainian territory. Unlike intra-European investment projects, where key risk is market volatility, in this case, the decisive role is played by the behavior features of the "Ukrainian side," war dynamics, and the probability of external control over nuclear energy.

In this chapter, for each scenario, probability assessments are presented, which were obtained in a separate analysis. The methodology for their calculation and input assumptions are deliberately not provided, as they require a separate article and do not fit within this work. Here, probabilities are used as input parameters for comparative scenario analysis.

The analysis shows: no realistic scenario worsens the project's economics. In most scenarios, its significance and profitability increase.

8.1. Ukraine's Economic Stagnation

Probability: ~95% (most probable scenario)

The most probable scenario is the continuation of the degradation loop, where industrial electricity consumption declines faster than the nuclear fleet amortizes. A persistent and long-term power surplus arises.

The internal market remains low-margin, and exports become the dominant source of income. Under these conditions, the HVDC interconnection in Poland transforms into a strategic channel for steady loading of Ukrainian nuclear power plants.

The economic necessity of exports is maintained regardless of the political situation. The interconnection's significance is maximal and stable over time.

8.2. Transfer of Ukrainian Nuclear Power Plants to Western Company Management

Probability: ~30%

Transferring nuclear generation to Western corporations or consortia increases institutional export predictability and reduces transaction risks.

External operators are oriented toward maximizing NPP loading and stable currency flows. This strengthens the export component and leads to increased stability and profitability of the HVDC interconnection.

8.3. Cancellation of the Green Agenda in the EU (Official or De Facto)

Two different mechanisms for canceling the green agenda are considered:

Official cancellation—public recognition of the course's erroneousness or impossibility of continuation under economic crisis conditions. Probability: <1%.

De facto cancellation—formal maintenance of the agenda with actual weakening of enforcement and priority shift, per the COVID-19 model. Probability: ~20%.

In both variants, reduced regulatory pressure will indeed lead to partial reconstruction of coal and gas generation. However, in parallel, industry reconstruction will begin, causing an increase in electricity demand and prices.

Consequently, cancellation of the green agenda—both official and de facto—does not reduce but increases the project's profitability. Cheap external power remains a critical resource, and the HVDC interconnection strengthens its role and generates additional rent.

8.4. Partial or Full Occupation of Ukraine by Russia

Probability: 10–15%

Even with partial or full occupation of Ukraine, the project's economic logic is preserved.

With high probability, a formally autonomous or puppet entity will be created in western oblasts, through which the EU can legally purchase electricity. Importantly, the main nuclear power plants are located precisely in western regions.

In this scenario, exports not only persist but increase. Russia is materially interested in export rent; using the interconnection for electricity supplies from Russia and Belarus is possible. Destroying the export channel provides no military benefits and directly reduces revenues.

8.5. Improvement or Deterioration of the Military-Political Situation

Probability: incorporated into all scenarios

Changes in the war's course do not carry critical threats to the project.

With situation improvement, exports stabilize. With deterioration, internal outage probabilities increase, but exports persist: historically, the population is disconnected, not external rent sources.

The HVDC infrastructure is located on Polish territory and is not subject to direct war risks.

8.6. Ukraine's Economic Miracle

Probability: <1% (least probable scenario)

The scenario of rapid economic growth in Ukraine is the only formally unfavorable for the project, as demand growth internally reduces export surplus.

Nevertheless, even in this case, export rent remains higher than internal prices, and part of the generation inevitably stays on external markets. With probability less than 1%, this scenario does not influence the project's investment assessment.

Monopolization of the Entry Point ("First Come, First Served")

EU regulatory practice does not permit arbitrary duplication of large inter-zonal introductions. If one HVDC interconnection creates sufficient capacity and closes the regional need, a second analogous project usually does not receive approval or is limited to insignificant volumes.

Consequently, the first launched HVDC interconnection obtains de facto monopolistic position for decades. This creates a persistent natural monopolistic rent, comparable to the economics of canals or large port hubs. All subsequent projects are either blocked or become economically secondary.

CHAPTER 9. Comparison with Alternative Investments in Dispatchable Power

Under dispatchable generation deficit conditions in the EU, the HVDC back-to-back project inevitably competes with several classes of investments: small modular reactors (SMR), hydropower plants, gas turbines, renewable energy sources, and energy storage.

The comparison is conducted within the nearest 10-year horizon, as it is precisely in this interval that the dispatchable power deficit is already shaped and requires practical solutions.

At the same time, it is not a comparison of technologies as such but an assessment of their ability to provide quick, scalable, and economically justified dispatchable power in the specified horizon. From this viewpoint, the HVDC project proves to be the only solution meeting all requirements simultaneously.

9.1. Small Modular Reactors (SMR)

SMR are a technologically promising direction, but their lifecycle is fundamentally incomparable with the considered horizon.

SMR technology is not yet industrially refined and is not applied in serial operation. Despite active development works, it remains at the pre-commercial stage and cannot be treated as a practical source of dispatchable power within 10 years.

Launch timeline—10–15 years, including licensing, site selection, environmental assessments, construction, and tests.

Cost—6–10 thousand euro/kW, making 2 GW installed power a project worth 12–20 billion euro.

No SMR in Europe will be launched by the end of the 2030s.

Thus, SMR cannot close the power deficit that exists now and is forecasted for the next decade. Within this comparison, SMR are considered a theoretical alternative but not a practical investment decision.

9.2. Hydropower Plants

Europe's hydropower resources are de facto exhausted. Every new hydropower plant requires multi-year environmental assessments, significant land flooding, and complex social approvals.

Potential for new hydropower plants in the EU—minimal.

Construction of large hydropower plants in mountain regions—politically almost inadmissible.

Implementation timelines—8–12 years.

From an economic viewpoint, hydropower is not a quick or scalable instrument for solving the dispatchable power deficit within a 10-year horizon.

9.3. Gas Turbines

Gas generation is the fastest way to create dispatchable power but encounters triple constraints:

high gas prices and supply uncertainty;

increasing CO_2 prices, making operation costly; political constraints within the EU.

Even with quick construction of gas-turbine blocks (2–3 years), LCOE remains undetermined and sensitive to external shocks. Furthermore, gas turbines do not remove network bottlenecks and do not provide cheap baseload power, unlike exports of Ukrainian nuclear generation via HVDC.

9.4. Renewable Energy Sources

RES increase electricity production but do not create dispatchable power.

Wind generation depends on weather conditions; solar generation does not cover evening peaks; additional RES installations deepen network constraints.

This means that 2–4 GW of RES is not equivalent to 2–4 GW of dispatchable power but only increases overall electricity volume without solving peak load issues.

9.5. Energy Storage

Storage is an important system element but does not create power, only redistributes it over time.

Cost—350–450 €/kW·h, making creation of a storage capable of operating 4–6 hours at 2–4 GW power economically unrealistic (capital expenditures—tens of billions of euro).

Storage does not generate energy but only smooths peaks. It is a useful auxiliary tool but cannot replace cheap external generation on which the HVDC interconnection's economics are based.

9.6. Comparison According to Key Parameters

Criterion	SMR	Hydropower (HES)	Gas Turbines	RES	Energy Storage	HVDC Back-to-Back
Implementation Time	10–15 years	8–12 years	2–3 years	1–3 years	1–3 years	2–3 years
CAPEX for 2–4 GW	12–20 bn €	5–10 bn €	2–4 bn €	—	30–50 bn €	1–1.2 bn €
Dispatchable Power	Yes	Yes	Yes	No	No	Yes
Risk of Delays / Regulatory Barriers	High	High	Medium	Low	Medium	Low
Scalability to 4 GW	Limited	Low	High	N/A	Low	High
Economic Rent	Medium	Low	Low	None	None	Very High

9.7. Conclusion

Within a 10-year horizon, HVDC back-to-back possesses a unique combination of properties: minimal CAPEX; minimal implementation time; direct linkage to already existing cheap generation; high institutional resilience; scalability to 4 GW; structural rent.

No other type of investment creates comparable dispatchable power volume in such a short time and with such predictable profit. This makes the HVDC interconnection not only competitive but the dominant solution for eliminating the dispatchable power deficit in the EU.

CHAPTER 10. Conclusion

Analysis of technical, economic, and institutional parameters shows that constructing an asynchronous HVDC back-to-back interconnection between Ukraine and the EU on Polish territory represents the only realistic variant for rapidly increasing dispatchable power in Central Europe. Unlike alternative investments—nuclear energy, gas turbines, hydropower, renewable energy sources, or storage—this project combines three features that are extremely rare in contemporary European electricity: speed of implementation, scalability, and economic stability.

The project is based on objective structural factors: slow amortization of Ukrainian nuclear generation, chronically low internal demand, persistent price differentiation between markets, and institutional stability of the "Ukrainian side's" interests, ensuring export flow predictability. In all development scenarios—Ukraine's economic reconstruction, stagnation, security deterioration, increased external control, or even change in sovereignty over parts of territories—export rent is preserved or grows. This grants the project exceptional resilience compared to any European new generation initiatives.

Locating the HVDC station in Poland eliminates key risks: political pressure, possibility of outages motivated by internal competition, vulnerability to hostilities, and jurisdictional uncertainty on the Ukrainian side. The infrastructure becomes part of the EU's electricity system and operates according to ENTSO-E principles, while export rent division ensures long-term interest from all parties. At the same time, the project allows Poland to eliminate a key economic vulnerability: slow modernization of its electricity fleet and dependence on imports.

The project's cost—1–1.2 billion EUR—is multiple times lower than the cost of alternative power sources of comparable scale.

The decision to implement the project should be made as soon as possible, as natural monopolization of the entry point means the first realized project solidifies a dominant position for decades. The EU will not approve a parallel introduction of analogous scale if the power deficit is closed by the first line. The decision window is thus limited: a project approved today shapes the new energy architecture of the region and creates a long-term income stream comparable to operating the largest gas hubs or ports.

Considering the above, the HVDC back-to-back interconnection in Poland should be treated as a strategic investment, providing the European Union with access to cheap baseload power and Poland with an institutional, economic, and energy role as a key transit center for Central and Eastern Europe. It is one of the few projects capable of changing the power balance in Europe within a 2–3 year horizon.

CHAPTER 11. Sources and Literature

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