STRATEGIC HORIZON
ENERGY STATECRAFT · VOLUME 06 OF 08

The Technology Race

The ETGEM Matrix in full

Conventional technology assessment scores two things: whether it works and what it costs. Both matter and neither tells a government what it needs to know. A technology with excellent economics whose supply chain sits inside a single non-allied state is a different strategic proposition from one with identical performance and a distributed chain. This volume scores twenty-eight technologies on five dimensions, and reports what the pattern shows.

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EDITORIAL NOTE

What this volume is

Volumes 01 to 05 referred to the ETGEM Matrix without setting it out. ETGEM is the Strategic Horizon Energy Technology and Geopolitical Exposure Matrix, and this volume sets it out in full: the five dimensions, the scoring rubric, the complete technology list and the patterns that emerge. The scores are analyst judgements, but the rubric and the underlying concentration data are published so that a reader can reproduce the reasoning or contest a specific score on stated grounds.

That is deliberate. A framework that cannot be checked is marketing rather than method. Everything here is open access: the dimensions, the scoring rules, the Core Scores and the concentration data behind them. A reader who wants to reweight the matrix for a different decision context has what is needed to do so.

One caution before the numbers. These are analyst judgements informed by quantitative inputs, not calculations. A score of 3 is not a measurement. The value of the framework is that it forces the five judgements to be made explicitly and in the same terms across technologies, so that they can be argued with. A reader who disagrees with a score should be able to say which dimension and why.

EXECUTIVE SUMMARY

The argument in brief

- **The correlation is inverse and it is not coincidence.** Across twenty-eight technologies, the better the economics the worse the supply chain and geopolitical exposure. Cheapness is largely the product of the concentration that creates the exposure, which means the two dimensions cannot be optimised separately.
- **Networks are Europe’s exception, and the only one at scale.** European manufacturers hold roughly two-thirds of the global HVDC market; Hitachi Energy and Siemens Energy together take more than half of everything outside China. HVDC cable and converters are the highest-scoring category outside resource-bound technologies, and the constraint is capacity rather than ownership.
- **Unit-level scores flatter the position.** Heat pumps score 3.6 because over 80 per cent of European installations are assembled in Europe. Around 90 per cent of rotary compressors are Chinese. Score one layer down and 3.6 becomes 2.4. The same correction applies to wind turbines and electric vehicles.
- **The best-scoring technologies are the ones that cannot scale.** Pumped hydro, biomethane, geothermal and hydropower score highest on chain and exposure because they run on domestic resources. All four are constrained by geology or feedstock. Sovereignty and scale are in tension, and no framework resolves that; it can only make the trade visible.
- **Two dimensions produce recommendations that look correct and compound the problem.** Assessed on maturity and cost alone, utility solar scores 5 and 5. It is the right technology and the wrong dependency, and conventional assessment has no way to say so.

> SH VERDICT

The framework exists because the alternative is choosing well on two dimensions and losing on the other three. Europe did not deploy the wrong technologies. It deployed the right technologies without asking who owned them, and the instruments that funded the deployment had no field in which the question could be recorded. ETGEM is not a better cost model. It is an argument that the cost model was never the binding constraint, and that a public euro spent without a supply chain assessment is a euro spent on someone else's industrial strategy.

SECTION I

Why Two Dimensions Fail

Most technology assessment scores maturity and economics. Both are necessary. Neither captures the question a European decision-maker actually faces, which is what happens to this technology if the relationship with its principal supplier deteriorates.

The failure is not theoretical. In April 2025 China introduced export controls on seven heavy rare earth elements and on related compounds, metals and magnets. Export volumes fell sharply through April and May; carmakers in Europe and the United States could not obtain permanent magnets, and some cut utilisation rates or temporarily closed factories. After trade volumes recovered, European rare earth prices remained up to six times Chinese levels. Every conventional assessment of the affected technologies had scored them well, because on maturity and cost they were excellent.

A framework that cannot distinguish between a mature, cheap technology with a distributed chain and a mature, cheap technology with a single-country chain is not neutral. It is systematically biased toward the second, because concentration is what makes things cheap.

SH ASSESSMENT I/1

The bias is structural rather than ideological, which is why it survives good intentions. Economies of scale, integrated supply chains and state-supported capacity all lower unit cost and all increase concentration. A scoring system that rewards low cost therefore rewards concentration, and does so invisibly. Every European funding instrument that ranks projects on levelised cost has this bias built in and no field in which to record it.

Recommendation I/1-R — Any public funding instrument for energy technology above a material threshold should require a supply chain and geopolitical assessment alongside the technical and financial case, recorded as a separate score rather than folded into risk-adjusted cost. The requirement is procedural and cheap; its absence is why the last decade of European deployment deepened the dependency it was meant to reduce.

SECTION II

The Five Dimensions

The Energy Technology and Geopolitical Exposure Matrix scores each technology one to five on five dimensions, where five is most favourable for European strategic autonomy.

Dimension	What it measures	What a score of 1 looks like
Technology Maturity	Commercial readiness and operating record at scale	Laboratory or single-pilot stage with no commercial deployment
Economics	Delivered cost against the incumbent alternative, without subsidy	Multiples of the incumbent cost with no credible path to parity
Scalability	Whether output can grow at the rate the transition requires	Bound by resource, siting or manufacturing capacity that cannot expand
Supply Chain Concentration	Ownership of the stages of the chain, informed by the Herfindahl-Hirschman Index	A single state controls most stages, with no credible alternative source
Geopolitical Exposure	Whether concentration is held by an actor with the capability and demonstrated willingness to use it	Concentration held by a strategic competitor with a record of export restriction

Table 1. The five dimensions. The last two are what conventional assessment omits, and are scored separately because concentration and intent are different questions: an ally with a monopoly and a competitor with a monopoly are not the same exposure.

The scoring rubric

The same five-point scale applies to every dimension. The general interpretation is fixed; the criteria that place a technology on it are dimension-specific.

	General meaning	Supply Chain Concentration	Geopolitical Exposure
5	Strong strategic advantage	Domestic or intra-European at every material stage	No external actor can restrict supply
4	Favourable	Distributed across allied jurisdictions; no single state above 50 per cent at any stage	Concentration held by treaty allies with no history of restriction
3	Mixed or neutral	One state holds 50 to 70 per cent of a stage, or dominates one stage while others are distributed	Concentration held by a partner with divergent interests but no demonstrated use of leverage
2	Material disadvantage	One state holds above 70 per cent of a critical stage; alternatives exist but need years	Held by a strategic competitor without a demonstrated restriction on this product
1	Severe strategic disadvantage	One state holds above 80 per cent of most stages with no credible alternative in the decision horizon	Held by a strategic competitor with a demonstrated record of export restriction

Table 2. The scoring rubric. The two sovereignty dimensions carry explicit thresholds because they do most of the analytical work; maturity, economics and scalability follow the general scale and conventional definitions. Where a technology sits between two levels, the lower score is taken.

How the scores are formed

The Herfindahl-Hirschman Index is a quantitative input to Supply Chain Concentration, not the score itself. The index informs the judgement; analyst assessment integrates it with the number of chain stages held by a single actor, the documented history of weaponisation, the availability of credible diversification within the relevant decision horizon, and the consequences of disruption for the systems that depend on it.

The published Core Score weights all five dimensions equally. This is a deliberate choice rather than a claim that they are equally important. No single weighting is correct

across all decision contexts, and an equal-weighted headline number is transparent in a way that a proprietary weighting is not. Decision-specific weighting is expected: a defence ministry weights the last two dimensions heavily, a regulated utility weights economics and scalability, and the same technology receives different scores for different reasons. Both readings are correct for their own question.

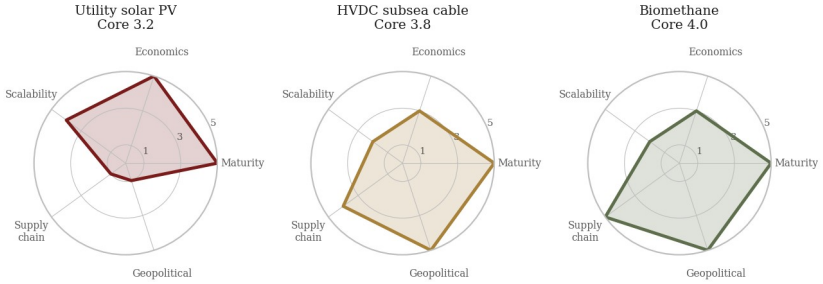


Figure 1. Three profiles with similar headline scores and entirely different shapes. Utility solar scores 5 on maturity and economics and 1 on both sovereignty dimensions. HVDC subsea cable is the inverse. Biomethane is strong everywhere except scale.

SECTION III

The Matrix

Twenty-eight technologies, scored on the basis set out above. Columns 1 to 5 are Technology Maturity, Economics, Scalability, Supply Chain Concentration and Geopolitical Exposure.

Generation	1	2	3	4	5	Core
Utility solar PV	5	5	4	1	1	3.2
Onshore wind	5	5	4	3	3	**4.0**
Offshore wind	4	3	3	3	3	3.2
Nuclear, Generation III	5	2	2	3	2	2.8
Advanced SMR	2	3	2	2	2	2.2
Geothermal	4	3	2	4	4	3.4
Hydropower	5	4	1	4	4	3.6
Storage	**1**	**2**	**3**	**4**	**5**	**Core**
Lithium-ion, grid scale	5	4	3	1	1	2.8
Sodium-ion	3	3	3	3	3	3.0
Flow batteries	3	2	2	2	2	2.2
Pumped hydro	5	4	2	5	5	**4.2**
Thermal storage	3	4	3	4	4	3.6
Networks	**1**	**2**	**3**	**4**	**5**	**Core**
HVDC converters	5	3	3	4	4	**3.8**
HVDC subsea cable	5	3	2	4	5	**3.8**
Large power transformers	5	3	1	3	4	3.2
Grid-scale power electronics	4	3	3	2	2	2.8
Fuels	**1**	**2**	**3**	**4**	**5**	**Core**

Generation	1	2	3	4	5	Core
Alkaline electrolysers	5	4	4	1	1	3.0
PEM electrolysers	4	2	3	3	2	2.8
SOEC electrolysers	2	2	2	4	4	2.8
Green ammonia	4	2	3	3	2	2.8
Sustainable aviation fuel	3	2	2	3	3	2.6
Biomethane	5	3	2	5	5	**4.0**
End use and materials	**1**	**2**	**3**	**4**	**5**	**Core**
Battery electric vehicles	5	4	4	1	1	3.0
Heat pumps	5	4	4	2	3	3.6
Industrial electrification	4	3	3	4	4	3.6
NdFeB permanent magnets	5	4	3	1	1	2.8
Battery mineral refining	5	4	3	1	1	2.8
Polysilicon and wafer	5	5	4	1	1	3.2

Table 3. The ETGEM Matrix, Core Scores at equal weighting. Bold entries score 3.8 or above. Sources for the underlying concentration data: IEA; World Bank; BloombergNEF; IRENA; MarketsandMarkets; Fastmarkets; European Heat Pump Association; company reporting.

The evidence behind the last two columns

The fourth and fifth columns carry the analytical weight, so the concentration data behind the extreme scores is given here rather than left implicit.

Score	Technology	Concentration evidence
1	Utility solar PV, polysilicon and wafer	Chinese share above 80 per cent at every stage from polysilicon to module
1	NdFeB permanent magnets	China holds roughly 90 per cent of rare earth processing and 85 to 94 per cent of magnet output, depending on scope. Export controls of April 2025 halted magnet supply to European carmakers; European prices stayed up to six times Chinese levels afterwards
1	Alkaline electrolysers	86 per cent of global alkaline manufacturing capacity; 60 per cent of total electrolyser capacity
1	Lithium-ion, battery mineral refining, BEVs	Chinese firms hold the largest share of cell manufacture and dominate cathode, anode and refining stages
3	Onshore wind	Chinese OEMs took the top five places globally in 2025, but European suppliers held 94.5 per cent of the European market and Chinese manufacturers supplied 446 MW into Europe, of which 278 MW in the EU-27
3	Sodium-ion	CATL, BYD and HiNa held about 55 to 60 per cent of global capacity in 2025 — concentrated, but the raw materials are not, and European, Indian, Japanese and American producers exist
4–5	HVDC converters and cable	European manufacturers hold roughly two-thirds of the global market; Hitachi Energy and Siemens Energy together take more than half of everything outside China; Prysmian, Nexans and NKT lead subsea cable
5	Pumped hydro, biomethane	Domestic resource, domestic engineering, no external chokepoint

Table 4. Concentration evidence for the scores at the extremes. Sources: IEA; World Bank; BloombergNEF; GWEC; Mordor Intelligence; MarketsandMarkets; Fastmarkets.

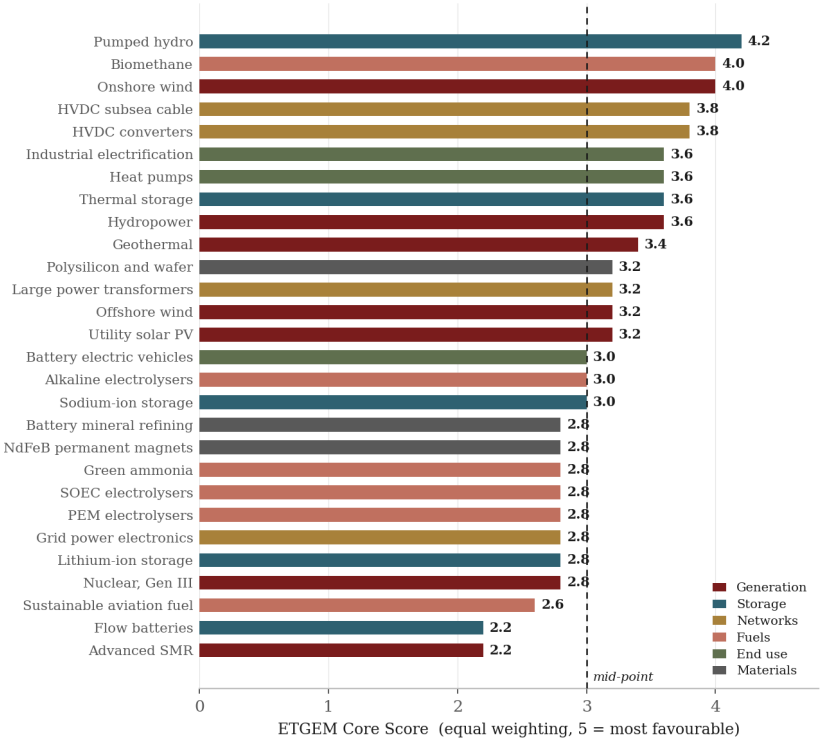


Figure 2. The full ranking. The mid-point line is where a technology is neither favourable nor unfavourable overall; roughly half the list sits below it.

SECTION IV

What the Matrix Shows

The inverse correlation

Plot economics against the average of the two sovereignty dimensions and the relationship is visible without statistics. The technologies with the best cost position have the worst exposure, consistently, across categories.

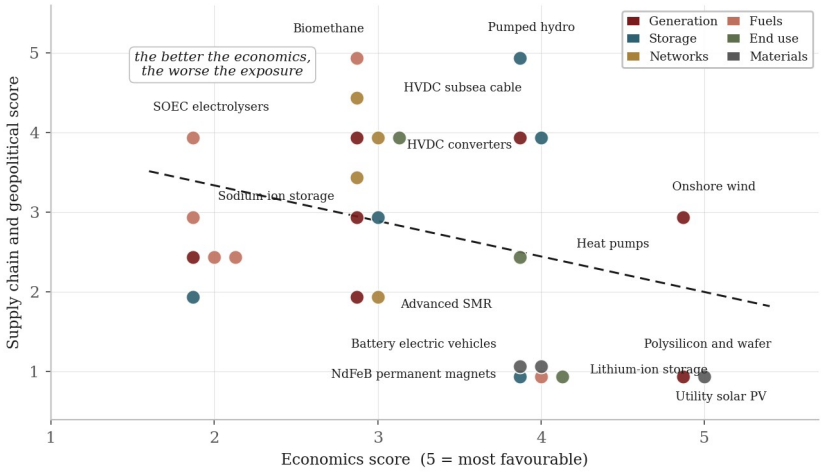


Figure 3. Economics against supply chain and geopolitical exposure, twenty-eight technologies. Points are offset slightly where scores coincide. The dashed line is an indicative trend across ordinal analyst scores, not a fitted statistical model; no significance should be read into its slope.

SH ASSESSMENT IV/1 — THE CENTRAL FINDING OF THIS VOLUME

The inverse relationship is structural rather than coincidental, and that is what makes it hard. Chinese solar, batteries and electrolysers are cheap because of scale, vertical integration and sustained state support — the same three factors that produced the concentration. The cost advantage and the exposure are the same fact seen from two directions. A European strategy that wants the first without the second is asking for a different industrial history.

The mechanism is stated as interpretation, not as identification. Twenty-eight ordinal scores assigned by one analyst cannot establish causation, and this volume does not claim they do. What Figure 3 shows is a structural pattern consistent with a well-documented industrial history; the reader is entitled to propose a different mechanism for the same pattern.

The practical consequence is that trade-offs must be chosen rather than discovered. Deploying the cheapest available technology is a defensible decision if taken knowingly and paired with a mitigation — stockpiles, second sources, content conditions. It is indefensible when taken because the assessment framework had no field for the question. Volume 01 to Volume 05 record three cases of the latter and none of the former.

The assembly illusion

Some of the more comfortable scores in Table 2 do not survive a second look. Over 80 per cent of heat pumps installed in Europe are assembled in the region, against roughly 10 per cent from China, and more than 90 per cent of indoor units are European. That supports a score of 3.6. But around 90 per cent of global rotary compressor manufacturing capacity sits in China, and the IEA describes this as an acute supply chain vulnerability.

Onshore wind shows the same shape from the other direction. European suppliers held 94.5 per cent of the European market in 2025, up 2.5 points on the previous year, and Chinese manufacturers delivered 446 MW into Europe against a global picture in which Chinese OEMs took the top five places worldwide. The turbine is European. The permanent magnet inside the generator is not.

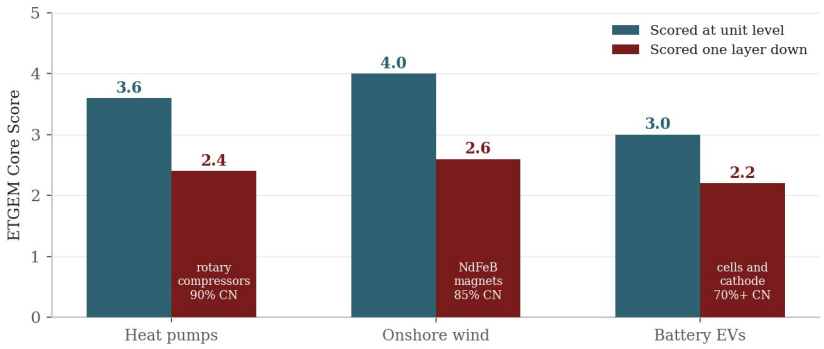


Figure 4. Three technologies scored at the level policy usually measures, and at the level where the concentration actually sits.

SH ASSESSMENT IV/2

Assembly is where the jobs are and components are where the leverage is, and European industrial statistics are built to count the first. A heat pump assembled in Poland from a Chinese compressor is a European manufacturing success by every metric the Commission publishes and a Chinese chokepoint by the only metric that

matters in a crisis. The Industrial Accelerator Act requirement that hydronic heat pumps originate in the Union three years after entry into force addresses the assembly layer, which is the layer that was not the problem.

Recommendation IV/2-R — Score and regulate at the component layer, not the unit layer. Content requirements should specify the stages that carry the concentration — compressors, magnets, cells, wafers — rather than final assembly, which relocates easily and secures nothing. Where a component cannot be sourced in Europe within the decision horizon, the honest response is a stockpile and a second source, not a domestic content rule that will be met by screwdriver plants.

The hedge that scores better than expected

One result runs against the pattern and deserves separate mention. Sodium-ion scores 3.0, above lithium-ion at 2.8, despite being a less mature and less energy-dense chemistry. The reason is that its raw material base — sodium from seawater or mined salt, iron, aluminium, hard carbon from agricultural residue — carries none of the concentration that lithium, cobalt and graphite do. Manufacturing is concentrated in China, where CATL, BYD and HiNa held around 55 to 60 per cent of global capacity in 2025, but that is a manufacturing concentration rather than a resource one, and European, Indian, Japanese and American producers are active. For stationary storage, where the energy density penalty matters least, sodium-ion is the clearest available hedge against the lithium chain — and it is not treated as one in European storage policy.

The scalability trap

The four highest-scoring technologies on the sovereignty dimensions — pumped hydro, biomethane, geothermal and hydropower — share a property. They run on domestic resources, which is why they score 4 or 5 on chain and exposure. They are also all bound by geology, siting or feedstock, which is why none of the four scores above 2 on scalability.

SH ASSESSMENT IV/3

Sovereignty and scale are in tension, and the framework cannot resolve it. It can only stop the trade being made by accident. Europe cannot run its energy system on biomethane and pumped storage; the resource is not there. It can run more of its system on them than it currently plans to, and the reason it does not is that these technologies lose on cost comparisons against imported alternatives whose exposure is not priced. Correctly scored, a portfolio weighted toward domestic-resource technologies buys insurance that the cost comparison does not show.

Recommendation IV/3-R — Set a floor rather than a target: a minimum share of European firm and flexible capacity that must run on domestic or overland resources, applied irrespective of comparative cost. Volume 03 recommended the same instrument for gas reserve cover. This is the generation-side equivalent, and both are cheap to legislate and impossible to retrofit after the assets are built.

SECTION V

Using the Matrix

Three cautions on application, each of which has produced an error somewhere in the last decade.

— **The Core Score is a starting point, not an answer.** Equal weighting is transparent, not correct. A grid operator procuring transformers and a defence ministry procuring magnets face different questions and should apply different weights. The framework is designed to be reweighted; a single ranking used across all decisions reproduces the problem it exists to solve.

— **Scores move, and the two sovereignty dimensions move fastest.** Rare earth processing was scored as concentrated but stable until April 2025 demonstrated otherwise. Bloomberg Intelligence now projects Chinese share of neodymium-praseodymium falling from 90 per cent in 2024 to 69 per cent by 2030, which would move NdFeB magnets by a full point on both dimensions. Quarterly revision is not administrative diligence; it is the only way the last two columns stay true.

— **A low score is not a recommendation against.** Utility solar scores 3.2 and Europe should keep deploying it. The score says that deployment without mitigation is a decision with a cost, and names the cost. Nothing in this framework argues for slower decarbonisation; it argues for decarbonisation with the supply chain question answered rather than deferred.

On reweighting

The matrix is designed to be reweighted rather than cited. Table 3 gives every input, so any reader can recompute the ranking for a different set of priorities and see how far the order moves. Strategic Horizon’s view is that a framework whose weights are hidden cannot be argued with, and a framework that cannot be argued with is not analysis. That is why the arithmetic is here rather than described.

SECTION VI

Strategic Implications

Ref.	Recommendation	Addressee	Horizon
I/1-R	Require a supply chain and geopolitical assessment for public energy technology funding above a material threshold, scored separately from cost.	Commission / EIB / member states	Immediate
IV/2-R	Regulate at the component layer: compressors, magnets, cells, wafers — not final assembly.	Commission / DG GROW	Immediate
IV/3-R	Set a floor for firm and flexible capacity running on domestic or overland resources, irrespective of comparative cost.	Council / member states	2026–30
—	Adopt ETGEM or an equivalent five-dimension framework as a standing assessment instrument, with quarterly revision of the sovereignty dimensions.	Commission	2026–27

Figure 5. Consolidated recommendations. Bold entries are assessed by Strategic Horizon as the two that most change European outcomes.

SECTION VII

Conclusion — The Strategic Horizon View

This volume was written to answer a question the previous five kept raising. Volume 02 found Chinese electrification run as an industrial sovereignty programme. Volume 03 found American energy power built on supply as leverage. Volume 05 found the electrolyser chain settled while Europe wrote targets. In each case the European instrument was well designed and aimed at the wrong variable. ETGEM is an attempt to name the variable.

What the matrix is actually saying

Twenty-eight technologies produce one dominant pattern and three secondary ones. The dominant pattern is that cost and sovereignty trade off against each other, because the same industrial history produced both. The first secondary pattern is that European scores flatter the position wherever the measurement stops at the assembled unit. The second is that the technologies Europe controls most fully are the ones it can deploy least. The third is that the one storage chemistry whose raw materials are genuinely distributed — sodium-ion — outscores the one Europe is actually building around.

None of that is an argument for autarky, and the framework does not produce one. Every high-scoring technology in Table 3 is high-scoring partly because it is small. A European energy system built only on what Europe controls would be a smaller and poorer system. The argument is narrower: that the trade between cost and control should be made deliberately, priced, and mitigated — and that for fifteen years it was not made at all, because no instrument in the European toolkit had a place to record it.

The verdict

STRATEGIC HORIZON VERDICT

Europe has not been choosing badly between technologies. It has been choosing well on two dimensions and not choosing at all on the other three. Solar, batteries and electrolysers were the right technical calls. The dependency they carried was never scored, never priced and never mitigated, and the reason is procedural rather than intellectual: the funding instruments had no field for it. That is a fixable failure, and fixing it costs almost nothing compared with what it has already cost.

The one genuine European position at scale is in networks, and it is the least discussed. European manufacturers hold roughly two-thirds of the global HVDC market. Hitachi Energy and Siemens Energy take more than half of everything outside China, and Prysmian, Nexans and NKT dominate subsea cable. The constraint there is capacity, not ownership — offshore HVDC cable order backlogs extend beyond four years — and capacity is the kind of constraint European capital can actually solve. Volume 01 argued that the grid is the contest still open. The matrix is where that claim stops being an opinion.

The framework's real function is to make a specific evasion harder. It is comfortable to argue about which technology wins, because that argument has no owner and no deadline. It is uncomfortable to ask who owns the chain, because the answer is usually known and the remedy is usually expensive. ETGEM does not make the remedy cheaper. It makes the evasion visible, which is the most a framework can do.

On the limits of this volume

These are analyst judgements against a published rubric, not measurements, and the scores should be read as such: a technology scored 3 is not empirically distinct from one scored 3.2, and the inverse relationship in Figure 3 is a structural observation rather

than a causal finding. Concentration figures underlying the fourth and fifth columns vary by source and by segment definition — Chinese share of NdFeB magnet production is reported between 85 and 94 per cent depending on scope, and both ends are consistent with a score of 1. The Core Score weights all dimensions equally, which no decision context actually justifies; it is published because it is transparent, not because it is right. And the sovereignty dimensions are the most volatile: any score in the last two columns is a statement about August 2026 and should be revisited quarterly.

Principal sources: International Energy Agency (Rare Earth Elements; Heat Pump Monitor 2026; Building the Future Transmission Grid; Global Hydrogen Review); World Bank ESMAP; BloombergNEF; Bloomberg Intelligence; IRENA; Fastmarkets; MarketsandMarkets; Mordor Intelligence; European Heat Pump Association; European Commission Joint Research Centre; PatSnap; company reporting. © Strategic Horizon 2026. Volume 06, v1.3. Open access. Reviewed by Ciceró and Solon; see the note on limits in Section VII.