Appendix — Methodology And Scoring Reference

This appendix documents, for each of the six dimensions, the quantity measured, the underlying data source and metric, and the formula by which that metric is mapped to a score. It is intended as a reference; analytical discussion is confined to the six dimension reports and the final report.

Scores as of July 16, 2026. **Networks:** Bitcoin, Ethereum, Solana. **Scale** 0–1; higher is more decentralized.

CONTENTS

A.0 Introduction And scoring framework
A.1 D1 · Ownership Distribution
A.2 D2 · Exit Fluidity
A.3 D3 · Network Verification Overhead
A.4 D4 · Critical Resilience Threshold
A.5 D5 · Blockchain Reconstruction Overhead
A.6 D6 · Geographic And Provider Resilience

APPENDIX A.0

Introduction And Scoring Framework

The ARK/Glassnode decentralization assessment scores Bitcoin, Ethereum, and Solana on six independent dimensions of decentralization: ownership concentration (D1), exit friction (D2), verification cost (D3), entity control (D4), historical reconstruction cost (D5), and infrastructure dispersion (D6). This appendix consolidates the methodology in one place: for each dimension it records the quantity measured and its relevance to decentralization, the data sources and the construction of the input metric, the scoring formula together with the rationale for its selection over the alternatives considered, and the resulting scores with their principal intermediate values.

Each dimension scores the three networks independently on the interval 0 to 1, where 1 denotes maximum decentralization. The six scores are not aggregated into a composite index: a composite would impose an arbitrary weighting across dimensions that measure structurally different quantities, and the per-dimension profile—a network's characteristic shape across the six axes—is itself the analytical object. The scores are therefore reported jointly on a radar chart. Reference constants (floors, ceilings, tier weights) are calibration choices documented in the project's decision log; scores are comparative within this study rather than absolute measures of decentralization.

Each dimension employs one of two mathematical forms, selected according to the structure of its input data: an anchored log-inverse transform for scalar costs and times, and normalized Shannon entropy for distributions of shares.

PATTERN 1 — ANCHORED LOG-INVERSE TRANSFORM (D2, D3, D5)

Applied where the input is a single scalar cost or time spanning several orders of magnitude. A floor value corresponds to a score of 1; a reference ceiling corresponds to a score of 0.

$$S = 1 - \frac{\ln(X / X_{\text{floor}})}{\ln(X_{\text{ref}} / X_{\text{floor}})}, \quad S \text{ clipped to } [0, 1]$$

X	measured cost or time for the network under evaluation
X_{floor}	best-case anchor (score of 1)
X_{ref}	worst-case anchor (score of 0)

RATIONALE: The inputs span three to five orders of magnitude; under linear normalization, the two least costly networks would receive nearly indistinguishable scores. The logarithm converts multiplicative ratios into additive intervals.

PATTERN 2 — NORMALIZED SHANNON ENTROPY (D1, D4, D6)

Applied where the input is a distribution of shares across categories (cohorts, entities, or regions). The statistic measures evenness and is normalized such that a uniform distribution receives a score of 1.

$$H_{\text{norm}} = \frac{-\Sigma_i p_i \ln p_i}{\ln n}$$

p_i	share of category i (shares sum to 1)
n	number of categories
H_{norm}	1 = perfectly uniform, 0 = fully concentrated in one category

RATIONALE: Normalized entropy captures both the number of categories and the evenness of their shares in a single [0,1] statistic. The Gini coefficient exceeds 0.98 for all three networks (a consequence of the long tail of small balances) and therefore discriminates poorly, while the Herfindahl–Hirschman Index is dominated by the single largest share. Entropy is applied identically across D1, D4, and D6 for internal consistency. *The logarithm base cancels in the ratio, so ln and log₂ yield the same result.*

APPENDIX A.1

D1 · Ownership Distribution

D1

Ownership Distribution

Concentration of coin and token supply across holders

SHANNON ENTROPY

WHAT IT MEASURES

The concentration of circulating supply across ten wallet-size cohorts. A more even distribution across cohorts is interpreted as broader ownership.

The underlying question is whether the asset is held predominantly by a small number of very large wallets or spread broadly across participants of different sizes. Glassnode partitions all on-chain addresses into ten wallet-size cohorts, ordered from smallest to largest, and reports each cohort's share of total circulating supply at daily resolution. A perfectly decentralized structure would show roughly equal supply share across cohorts; a concentrated one shows most supply in the largest cohorts. Unlike infrastructure metrics, ownership distribution shifts continuously as participants transact, so a smoothing window is applied before scoring to capture structural patterns rather than short-term flows.

RELEVANCE TO DECENTRALIZATION

Concentrated ownership carries governance weight in proof-of-stake systems, where large token holders exert proportionally greater influence over protocol upgrades and validator selection; it lowers the cost of accumulating a stake sufficient for a liveness or finality attack; and it compounds the operator-level concentration measured in D4 when large holders are also large staking entities.

DATA SOURCE & METRIC

Glassnode — Relative Address Supply Distribution (BTC / ETH / SOL). The input comprises the ten cohort supply shares at daily resolution, smoothed with a 90-day simple moving average (minimum 30 observations) and re-normalized to sum to 1.

Cohort boundaries are defined in native units, from below 0.001 up to above 100,000 coins. The 90-day window was the selected horizon. The scored snapshot is the 90-day window ending on July 15, 2026.

SCORING FORMULA

$$H_{\text{norm}} = \frac{-\sum_{i=1}^{n} p_i \ln p_i}{\ln n}, \quad n = 10 \text{ cohorts}$$

p_i	supply share held by cohort i (e.g. "1–10 BTC", ">100k SOL")
n	cohort count, fixed at 10
HHI	$= \sum p_i^2$, computed as an intermediate diagnostic; it agrees with entropy on the ordering of the networks but does not enter the score

SELECTION: Entropy was preferred to the HHI, the Gini coefficient, and the top-two-cohort ratio. The Gini coefficient exceeds 0.98 for all three networks, a consequence of the extreme tail of dust wallets, and therefore offers no discrimination. The top-two concentration ratio—the method's predecessor—discards the information in eight of the ten cohorts and is sensitive to the provider's cohort-boundary definitions. The HHI is dominated by the largest cohort's squared share rather than the full distributional shape; it is retained as an intermediate diagnostic because it agrees with entropy on the ordering of the three networks across all tested smoothing windows, providing mutual validation. Shannon entropy satisfies the axiomatic requirements of a distributional measure—continuity, maximality, and additivity — and is applied identically across D1, D4, and D6.

RESULT — FINAL D1 SCORE

BITCOIN:	ETHEREUM:	SOLANA:
0.7959	0.7435	0.5346

INTERPRETATION: Bitcoin's supply is the most evenly dispersed of the three, with the bulk held in mid-size cohorts; Ethereum is intermediate; Solana is the most concentrated, with the largest cohort (>100k SOL) alone holding roughly 59% of supply. The intermediate HHI diagnostic (BTC 0.1837, ETH 0.2144, SOL 0.4052) agrees with this ordering. One caveat applies: cohorts aggregate by wallet size, not by controlling entity—Ethereum's largest cohort contains the Beacon-Chain deposit contract and exchange cold wallets, which likely overstates true ownership concentration.

APPENDIX A.2

D2 · Exit Fluidity

D2 Exit Fluidity

Time required for a 1% participant to exit

LOG-INVERSE

WHAT IT MEASURES

The time required for a holder of 1% of stake (proof-of-stake) or 1% of hash rate (proof-of-work) to exit fully, whether by redirecting hash rate or by unstaking and withdrawing. The 1% threshold is chosen to represent an actor large enough to be systemically meaningful yet small enough to be operationally plausible.

The mechanism differs by chain. A Bitcoin miner redirects hash rate by pointing ASIC firmware at a new pool stratum server, a software change completing in under 30 seconds regardless of position size. An Ethereum staker must submit a voluntary exit and then wait through two sequential delays: the exit queue, processed at a fixed daily churn rate, and the withdrawal sweep, during which the protocol cycles through all validators before crediting balances. A Solana delegator submits a deactivation instruction and waits for the next epoch boundary, a delay identical for any position size. The scope is strictly the exit—from the decision to leave until funds are available; re-entry is excluded, isolating the lock-in cost of the current position.

RELEVANCE TO DECENTRALIZATION

Exit speed is the mechanism that makes pool and validator competition meaningful: a participant who can leave in seconds can credibly discipline a misbehaving operator, whereas one facing weeks of lock-in cannot. The exit time also bounds the attack window under stress, since when a dominant entity misbehaves, honest stake can drain away only as fast as the protocol permits.

DATA SOURCE & METRIC

BTC—pool stratum switch (Hash Rate Index); 1% hash rate threshold from Glassnode Mean Hash Rate. **ETH**—exit-queue series (ValidatorQueue) + protocol withdrawal-sweep model + active validator count. **SOL**—epoch-boundary stake deactivation (Anza / Solana). The input is the PERT-weighted effective 1% exit time, expressed in hours.

Bitcoin's stratum-switch latency is volume-independent and confirmed at under 30 seconds; the 1% hash rate threshold is 9.45 EH/s on the 90-day SMA (945.03 EH/s, 2026-07-15). The Ethereum queue series comprises 1,035 daily observations (2023-05-21 to 2026-03-27) sourced from beaconcha.in; the 1% staked-supply threshold is 403,000 ETH on the current ~40.3M ETH staked. Solana deactivation is volume-independent, with epochs running reliably close to 48 hours and no deactivation queue; 1% of staked supply is approximately 4.28M SOL.

SCORING FORMULA

$$t_{\text{exit}}(1\%) = t_{\text{queue}}(Q_{1\%}) + t_{\text{sweep}} \quad \text{ETH; BTC} = 30\,s,\ \text{SOL} = \text{next epoch}$$

$$t_{\text{sweep}} = \frac{N_{\text{validators}}}{16 \times 7{,}200}$$

$$t_{\text{eff}} = \frac{5\,t_{\text{typical}} + t_{\text{worst}}}{6} \quad \text{PERT estimator}$$

$$S_{\text{exit}} = 1 - \frac{\ln(t_{\text{eff}}+1)}{\ln(T_{\text{ref}}+1)}, \quad T_{ref} = 2{,}000\ h$$

t_{eff}	effective 1% exit time in hours, the PERT blend of the typical and worst cases
t_{sweep}	Ethereum withdrawal-sweep delay; 16 withdrawals/block × 7,200 blocks/day
$Q_{1\%}$	1% of staked supply entering the exit queue
T_{ref}	zero-score anchor of 2,000 h (≈83 days), set above the longest observed exit cycle of 55.58 days

SELECTION: The Ethereum queue wait is modelled as a linear function of queue size fitted to the historical series (R^2 = 0.9996, against 0.527 for a log-linear alternative) and evaluated at the 1% threshold; the sweep delay follows analytically from the validator count. The PERT estimator is a standard three-point blend that weights the central scenario five-to-one against the tail, pricing in the September 2025 congestion event (queue peak 2.67M ETH, 55.58-day exit cycle) without letting it dominate. T_{ref} = 2,000 h is set above that worst observed cycle (1,334 h) to provide headroom for future congestion events. A logarithmic transform is required because exit times span five orders of magnitude across the chains.

NOTE: For BTC and SOL the exit time is independent of volume ($t_{typical} = t_{worst}$), and the PERT estimator reduces to the constant exit time; only ETH's exit time scales with queue depth.

RESULT — FINAL D2 SCORE

BITCOIN:	ETHEREUM:	SOLANA:
0.9989	0.1785	0.4592

INTERPRETATION: Bitcoin scores near the maximum (t_{eff} ≈ 30 s): there is no protocol lock-in, queue, or sweep. Solana's exit is protocol-defined at one epoch boundary (t_{eff} = 60 h); its 9%-per-epoch deactivation cap has never been triggered, so the worst case is a longer epoch rather than a different mechanism. Ethereum's score reflects two compounding delays: the queue wait at the 1% threshold plus an irreducible withdrawal-sweep floor (P50 ≈ 7.6 days at the current ~880,000 validators), blended with the 2025 tail event to t_{eff} = 514 h. Liquid-staking tokens offer a secondary-market bypass, but at 1%-of-supply scale the slippage is material; D2 scores the base-layer path.

APPENDIX A.3

D3 · Network Verification Overhead

D3 Network Verification Overhead

Hardware cost of independent chain verification

LOG-INVERSE

WHAT IT MEASURES

The one-time hardware cost of operating a node that independently verifies the chain. A lower cost implies that trustless verification is accessible to a larger population of operators. For Solana, validator nodes rather than RPC nodes form the basis of comparison.

The full node is defined per chain as the minimum configuration that validates the current state and enforces all consensus rules: for Bitcoin, a Bitcoin Core node holding the complete UTXO set and history (~753 GB); for Ethereum, an execution-layer client plus a consensus-layer client (~1.2 TB); for Solana, an Agave or Firedancer validator whose binding constraint is memory rather than disk. The pruned tier is the minimum-viable configuration for personal verification: ~7 GB for Bitcoin (a client configuration constant), ~830 GB for Ethereum after pre-Merge history expiry, and ~2.5 TB of disk for Solana — where pruning reduces disk but cannot reduce the memory floor.

RELEVANCE TO DECENTRALIZATION

The ability to verify every transaction without a trusted third party is the foundational property of a public blockchain; at a few hundred dollars, millions of individuals can audit the chain, while at tens of thousands verification becomes the province of professional infrastructure. Hardware cost also determines whether nodes can run on consumer equipment in residential settings—harder to identify and seize than data-center deployments (D6)—and rising node costs concentrate validation among fewer, larger operators, compounding the entity-control risks of D4.

DATA SOURCE & METRIC

Published node hardware requirements (Bitcoin Core / Ethereum clients / Anza-Solana), priced at verified July 2026 hardware prices. The inputs are the pruned-node and full-node costs for each chain, combined by geometric mean.

Requirements are taken from bitcoin.org, the Ethereum client documentation together with a 2026 operator field guide, and the Anza validator documentation, and are priced against live retail listings (component price indices and vendor quotes, verified July 2026). Production practice is cross-checked against infrastructure providers, which provision 384–512 GB ECC memory for Solana mainnet validators—confirming that the documented minimum is a floor rather than a production target.

SCORING FORMULA

$$C_{\text{combined}} = C_{\text{pruned}\,0.50} \times C_{\text{full}\,0.50} \quad \textit{equal-weight geometric mean}$$

$$S_{\text{node}} = 1 - \frac{\ln(C_{\text{combined}} / C_{\text{floor}})}{\ln(C_{\text{ref}} / C_{\text{floor}})}, \quad C_{floor}=\$50,\ C_{ref}=\$15{,}000$$

C_{pruned}	hardware cost of a minimum-viable pruned node
C_{full}	hardware cost of a full node
C_{floor}	$50, the cost of a Raspberry Pi–class verifier (score of 1)
C_{ref}	$15,000, the professional-infrastructure ceiling (score of 0); the score is truncated at zero, S_{node} = max(0, ·)

SELECTION: The anchors are fixed and domain-justified rather than derived from the three-chain sample: $50 approximates the cheapest single-board computer capable of verification, and $15,000 the cost above which node operation is confined to professional infrastructure. Fixed anchors prevent rank reversal if a network were added to the comparison and keep the score interpretable on an absolute scale. Alternatives were considered and rejected: linear min–max normalization fails to differentiate when the range exceeds roughly twenty-fold; exponential decay requires a tuning parameter with no principled basis; the reciprocal transform is unstable near zero; and rank-based scoring discards magnitude information entirely.

NOTE: The geometric mean is preferred to the arithmetic mean because it distinguishes a $100 pruned node paired with a $10,000 full node from a uniform $5,050 pair; the two configurations imply materially different accessibility despite an identical arithmetic mean. Solana's cost is bounded from below by its 512 GB ECC RDIMM memory requirement, which pruning does not reduce: the runtime holds the accounts database in a memory-backed store, so the requirement is architectural, grows with the number of on-chain accounts, and is unchanged under Firedancer.

RESULT — FINAL D3 SCORE

BITCOIN:	ETHEREUM:	SOLANA:
0.7493	0.5695	0.0022

INTERPRETATION: Bitcoin's combined cost is $209 (pruned $151, full $289) — consumer hardware throughout, with disk as the binding constraint. Ethereum's $583 (pruned $465, full $730) is driven by its 32 GB memory recommendation and 2 TB drive. Solana's $14,816 (pruned $10,900, full $20,140) sits essentially at the $15,000 reference ceiling, yielding a score of 0.0022; a single 512 GB ECC RDIMM kit alone exceeds $18,000 at July 2026 prices. Memory pricing is abnormally elevated by an AI-driven DRAM shortage, but the ordering is structural: even at pre-shortage prices, Solana's combined cost would remain an order of magnitude above Ethereum's.

APPENDIX A.4

D4 · Critical Resilience Threshold

D4 Critical Resilience Threshold

Number of entities required to reach a control threshold

NC + ENTROPY

WHAT IT MEASURES

The number of independent entities whose collusion would suffice to reach a critical consensus threshold: 51% of hash rate under proof-of-work, or 33% of stake (the liveness threshold) under proof-of-stake. The score combines the Nakamoto Coefficient with the evenness of the full entity distribution.

Where D1 measures concentration at the holder level, D4 measures it at the operator level: the entities that run consensus infrastructure. Entities are ranked by their share of consensus power—hash rate for Bitcoin, staked capital for Ethereum and Solana—and the Nakamoto Coefficient counts the minimum number whose combined share reaches the chain's critical threshold. Because the native thresholds differ (51% for proof-of-work, 33% for proof-of-stake liveness), raw coefficients are not directly comparable; a threshold adjustment projects them onto a common 50% basis before scoring.

RELEVANCE TO DECENTRALIZATION

If few entities control consensus power, they can halt block production (a liveness attack) or, at higher thresholds, finalize fraudulent state (a safety attack); concentrated control also enables censorship, whether through regulatory coercion of identifiable operators or voluntary cartel formation. The persistence of the risk differs by consensus type: Bitcoin miners can redirect hash rate between pools within a minute (D2), making pool concentration dynamic and self-correcting, whereas staking lock-ins make proof-of-stake concentration structurally more persistent.

DATA SOURCE & METRIC

BTC—mining-pool hash rate shares (Hash Rate Index). **ETH**—staking-entity shares (Rated.network, withdrawal-credential taxonomy). **SOL**—validator stake shares (Solana Compass / Everstake). The inputs are the ranked entity shares, from which the Nakamoto Coefficient and the share entropy are derived.

The Bitcoin distribution uses a 7-day pool window across 12 entity buckets including a residual; the Ethereum distribution classifies validators by withdrawal credential—the economic entity controlling the stake—across 24 buckets (March 2026 snapshot, corroborated as materially unchanged in June 2026); the Solana distribution ranks validators by active stake across 23 buckets (July 2026).

SCORING FORMULA

$$\mathrm{NC_e} = \mathrm{NC_{native}} \times \frac{T_{\mathrm{base}}}{T_{\mathrm{chain}}} \quad T_{base}=0.50$$

$$\mathrm{NNC} = \min\left(1, \frac{\log_2 \mathrm{NC_e}}{\log_2 \mathrm{NC_{ref}}}\right), \quad NC_{ref}=100$$

$$H_{\mathrm{norm}} = \frac{-\Sigma_i p_i \log_2 p_i}{\log_2 n}$$

$$\mathrm{D4} = 0.5 \times \mathrm{NNC} + 0.5 \times H_{\mathrm{norm}}$$

NC_{native}	raw Nakamoto Coefficient at the chain's native threshold
T_{chain}	native threshold: 0.51 (BTC), 0.33 (ETH, SOL); projected to a common T_{base}=0.50 basis
NNC	log-scaled, normalized coefficient; each doubling of the required number of colluding entities contributes one additional bit
NC_{ref}	100, the full-score reference (100 entities, each holding ≤0.5%)
p_i, n	consensus share of entity i, over n entity buckets including a residual "other" category

SELECTION: The threshold adjustment prevents the comparison from systematically disadvantaging proof-of-work, whose native threshold is higher. The logarithmic scaling of the coefficient reflects diminishing returns: raising the coefficient from 2 to 4 doubles the difficulty of collusion, while raising it from 50 to 52 adds little, so each doubling is treated as one additional bit of security, with NC_{ref} = 100 a realistic upper bound for independent consensus entities (no extant chain exceeds roughly 50). Entropy was preferred to the Gini coefficient (near-identical values for all chains), the HHI (collapses for distributions with many small participants), and the Theil index (requires additional normalization).

NOTE: The NNC term reflects the minimum number of entities required for control, while H_{norm} penalizes unevenness in the remainder of the distribution; the equal weighting captures both forms of concentration.

RESULT — FINAL D4 SCORE

BITCOIN:	ETHEREUM:	SOLANA:
0.5471	0.4934	0.6498

INTERPRETATION: Solana leads (NNC 0.7296, entropy 0.5699): nineteen validators must collude to reach 33%, and no single validator exceeds ~3.8% of stake, though the entropy term is depressed by the long residual tail. Bitcoin's entropy is the highest of the three (0.8600) — its pool distribution beyond the top entities is comparatively even—but its coefficient of 3 holds the composite at 0.5471. Ethereum's coefficient is also 3, with Lido's ~23% share depressing both components. Three qualifications apply: a pool's hash rate is pointed at it, not owned by it; Lido is a protocol whose stake is distributed across roughly 37 independent node operators, so the headline coefficient understates the coordination cost of an attack; and several Solana operators run multiple validator identities, putting the organization-level coefficient nearer 13–16.

APPENDIX A.5

D5 · Blockchain Reconstruction Overhead

D5 Blockchain Reconstruction Overhead

Five-year cost of operating nodes across all storage tiers

LOG-INVERSE

WHAT IT MEASURES

The total cost of ownership of operating nodes across the three storage tiers (pruned, full, and archive) over a five-year horizon. The dimension captures the cost of preserving the chain's complete history rather than only verifying its current state.

Where D3 measures the upfront cost of verifying the current state, D5 measures the cumulative cost of custodianship: the pruned tier (weight 0.30) is the minimum audit configuration, the full tier (0.50) the network backbone, and the archive tier (0.20) the deepest level of participation—the capacity to independently reconstruct and re-verify the chain's entire history. Annual costs cover both storage expansion driven by chain growth and memory upgrades driven by state growth, discounted over the five-year window.

RELEVANCE TO DECENTRALIZATION

A chain whose complete history can be independently verified for a few hundred dollars is structurally more auditable than one requiring tens of thousands of dollars in hardware. When archive nodes are unaffordable to individuals, historical data access consolidates onto a small number of infrastructure providers, creating censorship vectors and re-introducing trusted intermediaries precisely where the chain's history is concerned.

DATA SOURCE & METRIC

The hardware-pricing base of D3, extended with archive-node storage sizing. The input is each tier's five-year total cost of ownership, expressed as a net present value at a 5% annual discount rate and combined by weighted geometric mean.

Archive sizing follows each client's documented storage scheme: Bitcoin's archive coincides with its full node, since the complete chain fits a single consumer drive; Ethereum's archive occupies ~2 TB under Geth's path-based scheme (the legacy hash-based scheme exceeded 20 TB); Solana's unpruned ledger stands near 480 TB and grows by 80–120 TB per year, so its archive tier is priced on enterprise storage with a substantial annual expansion cost. Prices are held flat at the verified July 2026 level over the projection window.

SCORING FORMULA

$$\mathrm{TCO}_{5,\mathrm{tier}} = C_{\mathrm{upfront}} + C_{\mathrm{annual}} \times \frac{\Sigma_{t=1}^{5} 1}{(1.05)^t} \quad \textit{annuity factor} = 4.329$$

$$C_{\mathrm{combined}} = \mathrm{TCO}_{\mathrm{pruned}\,0.30} \times \mathrm{TCO}_{\mathrm{full}\,0.50} \times \mathrm{TCO}_{\mathrm{archive}\,0.20}$$

$$S_{\mathrm{D5}} = 1 - \frac{\ln(C_{\mathrm{combined}} / C_{\mathrm{floor}})}{\ln(C_{\mathrm{ref}} / C_{\mathrm{floor}})}, \quad C_{floor}=\$50,\ C_{ref}=\$150{,}000$$

$C_{upfront}$	upfront hardware cost for the tier
C_{annual}	annual storage-expansion and memory-upgrade cost as the chain grows
$weights$	full 0.50 (network backbone), pruned 0.30 (minimum audit capability), archive 0.20 (historical verifiability)
C_{ref}	$150,000, the zero-score anchor (ten times that of D3, reflecting the multi-tier five-year horizon); the score is truncated at zero, S = max(0, ·)

SELECTION: The five-year net-present-value treatment is standard capital budgeting: annual growth costs are discounted at 5% per annum (annuity factor 4.329), so that chains whose costs are dominated by recurring growth are compared fairly against chains whose costs are front-loaded. The tier weights order the roles by network importance—full nodes sustain consensus health, pruned nodes set the personal audit floor, archive nodes provide historical verifiability—and C_{ref} = $150,000 is ten times D3's ceiling, reflecting the extension from a single upfront purchase to three tiers over five years.

NOTE: The transform and geometric-mean construction follow D3, extended to three tiers over a five-year horizon. Solana's archive tier dominates its combined cost; Ethereum's archive requirement declined substantially under Geth's path-based storage scheme.

RESULT — FINAL D5 SCORE

BITCOIN:	ETHEREUM:	SOLANA:
0.7683	0.5862	0.2065

INTERPRETATION: Bitcoin's combined five-year cost is $319: every tier is consumer-grade, and the archive tier equals the full tier because the whole chain fits one drive. Ethereum's $1,374 benefits sharply from the path-based archive scheme, which brought the archive tier down to approximately the full tier's cost. Solana's $28,702 is dominated by its archive tier ($93,887 five-year TCO: $48,000 upfront plus ~$10,600 per year of ledger expansion and memory upgrades); even its pruned tier exceeds Bitcoin's archive tier by more than thirty-fold. A community project distributing the Solana archive as content-addressed files offers an alternative, at the cost of shifting trust to third-party data availability.

APPENDIX A.6

D6 · Network Geographic And Provider Resilience

D6 Network Geographic And Provider Resilience

Distribution of nodes across hosting types and regions

ENTROPY + BONUS

WHAT IT MEASURES

The resistance of the node and validator population to coordinated takedown, measured as its distribution across hosting categories (with a censorship-resistance adjustment for environments resistant to seizure) and across world regions.

The dimension asks: if a single government, cloud provider, or regional internet failure targeted the network's infrastructure, what fraction of consensus-enforcing nodes would survive? Scoring covers each chain's full-node layer—Bitcoin's reachable node set, Ethereum's execution-layer population, and all Solana validators and RPC nodes, which share one hardware floor. Bitcoin mining-pool nodes are excluded: they number below 0.6% of the reachable population, and a sensitivity test confirms that their inclusion would move the score by less than 0.001.

RELEVANCE TO DECENTRALIZATION

Nodes concentrated in one jurisdiction are exposed to sovereign action, and nodes concentrated on one cloud provider are exposed to a single terms-of-service change, outage, or seizure order. Nodes operating over Tor or behind residential connections are structurally harder to identify and disable than data-center deployments, creating an asymmetric defense whose strength scales with the fraction of the network invisible to surveillance; published infrastructure research further indicates that the large majority of inter-country cable routes would need to fail before a material fraction of Bitcoin's nodes disconnected.

DATA SOURCE & METRIC

BTC—Bitnodes country + hosting-type snapshot (source retired 2026-05-03; last verifiable 2026-04-27). **ETH**—Etherscan / Ethernodes. **SOL**—Solana Foundation / Helius / validators.app. The inputs are the hosting-category shares and the four macro-region shares.

Countries are grouped into the four macro-regions by standard geopolitical convention. The Bitcoin snapshot is the last verifiable crawl of its primary source (2026-04-27; the source retired in May 2026 and its successor publishes no hosting-category split, so the category shares are frozen at that snapshot); the Ethereum and Solana readings are live to July 2026.

SCORING FORMULA

$$S_{\text{host}} = 0.6 \times H_{\text{norm}}(\text{hosting}) + 0.4 \times \text{CR}_{\text{bonus}}$$

$$\text{CR}_{\text{bonus}} = 0.5 \times p_{\text{residential}} + 1.5 \times p_{\text{tor}} \quad \textit{capped at 1.0; data-center weight} = 0$$

$$S_{\text{geo}} = \frac{H(\text{regions})}{\log_2 4}, \quad H \textit{ over NA / EU / APAC / RoW}$$

$$\text{D6} = 0.5 \times S_{\text{host}} + 0.5 \times S_{\text{geo}}$$

$H_{norm}(hosting)$	normalized Shannon entropy over non-zero hosting categories (Data Center, Residential, Tor, Unknown)
CR_{bonus}	censorship-resistance adjustment, weighting Tor at 1.5 (locations unobservable and not subject to seizure), residential hosting at 0.5, and data-center hosting at 0; capped at 1.0
S_{geo}	region entropy over four macro-regions, with maximum entropy $\log_2 4 = 2.0$

SELECTION: Entropy alone treats hosting categories as interchangeable—a network hosted 100% in data centers, split evenly across three cloud providers, would score as highly as one balanced across data-center, residential, and Tor environments, despite radically different seizure profiles. The censorship-resistance term encodes this asymmetry: Tor nodes (weight 1.5) cannot be identified, located, or subpoenaed; residential nodes (0.5) require materially more effort to target than data centers (0); the cap at 1.0 binds only for Bitcoin, whose 63% Tor share yields a raw bonus of 1.02. Four macro-regions are used rather than countries because jurisdictional risk clusters regionally, physical cable topology operates at continental scale, and a country-level analysis would dilute the concentration signal. Bitcoin's regional entropy is computed over clearnet nodes only: Tor locations are unknown, and treating Tor as a fifth region would both penalize the network for its most censorship-resistant hosting and double-count a benefit already rewarded in S_{host}.

NOTE: Mining-pool full nodes (<0.6% of the population) are excluded. Tor nodes are excluded from S_{geo}, as their contribution is already reflected in S_{host}; for BTC, S_{geo} is accordingly computed over clearnet nodes only, Tor node locations being unobservable.

RESULT — FINAL D6 SCORE

BITCOIN:	ETHEREUM:	SOLANA:
0.8410	0.7111	0.3236

INTERPRETATION: Bitcoin leads on the hosting side (S_{host} 0.8491, S_{geo} 0.8329): its 63% Tor share is unmatched by any other chain. Ethereum has the strongest geographic balance of the three (S_{geo} 0.8528) but a moderate hosting profile (S_{host} 0.5693; roughly half its nodes are data-center hosted, with negligible Tor presence). Solana's score rests entirely on geography (S_{geo} 0.6472): with effectively 100% data-center hosting, its hosting distribution is a single category, so both the entropy term and the censorship-resistance term are zero and $S_{host} = 0$.

REFERENCE

All Scores At A Glance

DIMENSION	SCORING PATTERN	BTC	ETH	SOL
D1 · Ownership Distribution	Normalized Shannon entropy	0.7959	0.7435	0.5346
D2 · Exit Fluidity	Anchored log-inverse	0.9989	0.1785	0.4592
D3 · Network Verification Overhead	Anchored log-inverse	0.7493	0.5695	0.0022
D4 · Critical Resilience Threshold	Threshold-adj. NC + entropy	0.5471	0.4934	0.6498
D5 · Blockchain Reconstruction Overhead	Anchored log-inverse	0.7683	0.5862	0.2065
D6 · Geographic And Provider Resilience	Entropy + CR bonus	0.8410	0.7111	0.3236

Source: ARK Investment Management LLC, 2026, based on Glassnode and public network data. Scores are independent per dimension and are not combined into a composite index.