Validator Economics: Variable min validator deposit size

EF Academic Grant ID: FY23-1030

MILESTONE 1: IDENTIFICATION OF DATA SOURCES & INSIGHTS

Sandra Johnson
ConsenSys Software R&D

August 17, 2023

1 Overview

This document is the deliverable for Milestone 1 of EF Academic Grant ID: FY23-1030, and is joint work with Kerrie Mengersen and Patrick O'Callaghan. It details available information, data sources, existing and proposed visualisations that will provide relevant data insights to gain a deeper understanding of current validator economics and any intuitions or assumptions used in formulating proposed solutions for capping the number of validators.

The information gathering is targeted towards the proposal being evaluated, viz. a variable minimum validator balance, which is one of the proposals that Vitalik articulated in his blog post regarding single slot finality (SSF). As Vitalik summarises in his blogpost "Determining the validator economics" means "answering the question of who stays and who goes if demand for becoming a validator exceeds the system's capacity to process validators" and he adds that this question "involves the hardest tradeoffs that are not-just-technical and merits engagement from the community."

In other words, the floating minimum balance proposal is one of the ways put forward by Vitalik to manage a cap on the total number of validators. In this proposal, the validator with the lowest balance will be kicked out when the total number of validators is greater than the cap.

Vitalik highlighted a potential vulnerability that could be introduced with this proposal, viz. the emergence of a new type of griefing attack [8] where validators split their stake in order to push smaller validators out.

The consequence of such a successful griefing attack is that the wealthier validators increase their reward, R, because the total deposit amount, D, decreases. (Current formula to calculate the validator reward: $R = \frac{k}{\sqrt{D}}$).

Vitalik further suggests that this attack could possibly be mitigated by "adding a fee per validator slot, and target it so that under a Zipfian distribution this is never worth it. However, this would still leave open a potential vulnerability if the distribution becomes very non-Zipfian".

Many people have generously contributed time and data, provided insights and made helpful suggestions, which has been incredibly helpful in compiling the resources listed in this document. They include, but are not limited to Barnabé Monnot and the Rigorous Incentives Group (RIG) team, Andrew Breslin, Juan Dominguez, Justin Drake, Ben Edgington, Josh Fernandez, Paul Harris, Mikhail Kalinin, Abad Mian, Mike Neuder, Marta Poling, Roberto Saltini, Bogdan Suvar, Alexander Tesfamichael, Kuhan Tharmananthar and Rodrigo Vasquez.

2 EIP-7251: Increasing the MAX_EFFECTIVE_BALANCE

Recently a proposal has been put forward to increase the maximum effective balance of 32 ETH to 2,048 ETH. This proposal aims to encourage stakers to consolidate their stake which means a reduction in the number of validators that they run, which can potentially greatly reduce network load. This proposal overlaps with the validator capping proposal of having a variable minimum balance, which this Ethereum Foundation (EF)-funded project is analysing and modelling. It is therefore important to ensure that the EF grant research complements the work already undertaken to assess security risks and other aspects associated with increasing the maximum balance. The blog posts that propose and analyse the increased maximum effective balance are:

- Removing Unnecessary Stress from Ethereum's P2P Network, 10 May 2023 [5].
- Increase the MAX_EFFECTIVE_BALANCE – a modest proposal, 6 June 2023 [30].
- Security Considerations and Spec Changes for a MAX_EFFECTIVE_BALANCE Increase, 12 June 2023 [31].
- Upper bound on the probability of one majority dishonest committee in the context of MAX_EFFECTIVE_BALANCE increase, 21 June 2023 [33].
- There is currently an Ethereum Improvement Proposal (EIP) in draft form to implement the proposal to increase the maximum effective balance. Here is the pull request. The initial draft by Mike Neuder is in his GitHub repo: max effective balance increase proposal [29].
- Mike Neuder added a very useful FAQ post for EIP7251.
- Christine Kim publishes regular summaries of the *Ethereum All Core Developers (AllCoreDevs)* calls. *Call 111* and *Call 112* include the main discussion points for the proposal to increase the maximum effective balance for validators. Recordings of the meetings are available on YouTube. During *Call 111* the discussion around the increase in maximum effective balance starts around 59 mins (recording) and for *Call 112* the discussion starts around 46 mins (recording)

With this proposal validators can choose to auto-compound their stake, instead of having any rewards above the 32 ETH effective balance automatically withdrawn into their account. Therefore validators do not have to wait until 32 ETH has been accumulated before another 32 ETH deposit can be made, but they can automatically compound their stake with rewards earned. The flow-on effect is that this would increase their rewards since rewards are based on the effective balance of the validator, making it attractive to smaller, typically solo, stakers, who have to wait for a very long time to earn enough ETH for another 32 ETH stake. It should also be attractive to larger stakers who regularly earn far greater rewards, and instead of waiting for a newly created validator to be activated in the long activation queue, that stake will immediately earn additional rewards. On the other hand consolidation and compounding of validators run a risk of increased slashing penalties.

As part of this project it would therefore be prudent to analyse the overall design of this proposal, especially with respect to two key criteria: risk and benefit. In other words what are the risks for a range of stakers - from solo to large stakers, assuming some consolidate a portion or all of their stake, and what are the benefits for the various categories of stakers? Are the risks and benefits greater for some categories of stakers, and can we deduce the extent to which these potential differences affect various stakers and importantly the health of the ecosystem.

Having a better understanding of the implications of this proposal on the health of the network, would also better inform the minimum variable deposit proposal.

Note that a security analysis has already been undertaken by the EF (as mentioned above), but further in-depth analysis is desirable.

3 Data Insights

In order to analyse the variable minimum validator deposit proposal and the increase in the maximum effective balance proposal, it would be interesting to know, estimate or visualise the following:

- Committees - selection and rewards
- Staker wealth and distribution
- Validator rewards
- Validator yield
- Validator slashing and penalties
- Staked ETH as a percentage of ETH supply over time
- Assessment of potential griefing/discouragement attacks
- Assessment and projection of centralisation forces with respect to large stakers (both for EIP7251 and for this project)
- Health of the Ethereum ecosystem

3.1 Committees

There are two main types of committees [14]:

- Beacon committees
- Sync committees

Beacon committees are allocated to each epoch by the protocol in such a way that each slot has the same number of committees. All active validators are distributed equally among these committees. Within each committee a subset of validators, called aggregators, is chosen probabilistically based on Boneh–Lynn–Shacham (BLS) signatures, to help improve scaling by aggregating the committee's messages. The beacon committees are disbanded at the end of the epoch and a new randomly allocated set of committees is created for the next epoch. The protocol specifies a minimum size for a committee, as well as a maximum number of committees per slot [14].

Each slot typically has several committees, sometimes referred to as 'subcommittees' [31], and the same number of subcommittees is allocated to each slot in the epoch, and hence the total number of committees in an epoch is a multiple of 32 [14].

In contrast to the short duration of the committees where each validator attests once per epoch, sync committees, consisting of 512 validators that are chosen at random **with replacement** (i.e. although unlikely, a validator can be chosen more than once), persist for 256 epochs

(27.3 hours). When a proposer includes the sync committee's output, they receive a reward that is proportional to the reward of the whole committee [14].

The rewards for attestations and sync committee are split $\frac{7}{8}^{th}$ and $\frac{1}{8}^{th}$ between the validators performing these duties and the proposer that includes the evidence in blocks, respectively.

3.2 Staker wealth and distribution

Validators can stake their ETH in four different ways [6]. The links provide a more detailed description of the options available for stakers, and figures 1 and 2 on page 5 - 5 visualise the different ways of staking.

- Solo staking [16]
- Staking as a service (Saas) [17]
- Pooled staking - "many of these options include what is known as 'liquid staking' which involves an ERC-20 liquidity token that represents the staked ETH." [15]
- Centralised exchanges [18]

The Ethereum Foundation provides a *Comparison of staking options*, outlining the key differences between solo staking, staking as a service and pooled staking. The legal implications of staking are discussed in Consensys blog post *Staking is Data Validation, Not Investment* [12].

Re-staking is deemed to be out of scope for this grant research topic, but there are good resources to explain the concept and discuss the implications of re-staking. A blog post by Buterin *Don't overload Ethereum's consensus* discusses the various approaches to re-staking and explains why some techniques bring "high systemic risks to the ecosystem" [9]. Another interesting perspective is from the Substack post by Tripoli: *Endgame Perils of Restaking*, and the addendum to the post: *Addendum: Endgame Perils of Restaking*.

We can at best have an informed guess about current staker wealth distribution. Some staking pools can be identified, but even then we may not be aware of all of the validator nodes and validators that they run. However, the largest staking pool, Lido, is transparent regarding its overall control of validators. Lido operates on a trusted setup, and Consensys staking runs several Lido operators.

The Ethereum Foundation and EtherScan conducted a survey of stakers [34], according to the following categories: solo staking, staking pool service, mini node operator (Rocketpool), and those not yet staking. The responses were analysed and the key trends, take aways, and predictions reported. The large majority of the respondents were either solo stakers or mini pool operators.

Justin Drake and Mike Neuder also had conversations with stakers with the biggest stakers that they talked to being Coinbase, a few different Lido operators and Kraken. They concluded that there are probably a few reasons to motivate bigger stakers to consolidate their validators if the maximum deposit size is increased from 32 ETH to 2,048ETH. Arguably this proposal is aimed largely at the bigger stakers rather than the smaller, solo stakers. The reasons they may want to consolidate are: to reduce operational cost, although it is likely not particularly high infrastructure costs, Mike Neuder estimated in the region of a few $100 per week, but key management would be the more challenging side of running many validators that can be consolidated into fewer validators if this proposal is implemented. The questions raised by LIDO and the responses provided by the EF are in the documents listed on page 2.

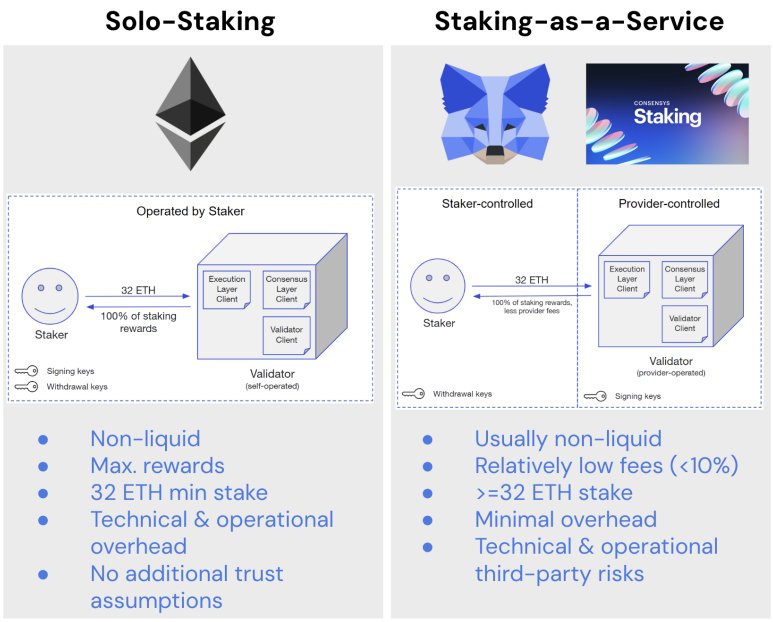


Figure 1: Solo staking, staking as a service (credit: Andrew Breslin)

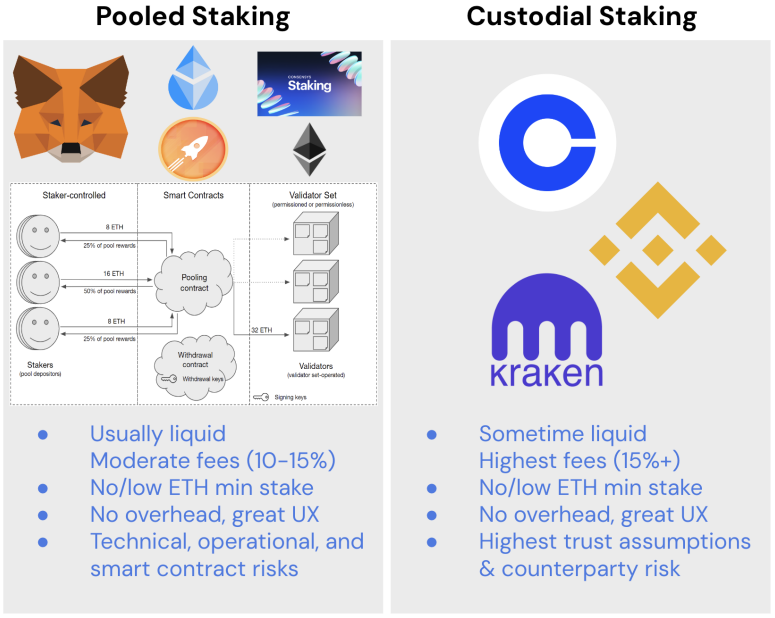


Figure 2: Pooled staking, Custodial staking (credit:Andrew Breslin)

3.3 Validator rewards

By participating in Ethereum's consensus, honest validators earn rewards in two ways[6]:

- consensus layer (CL) rewards, described in more detail below.
- execution layer (EL) rewards are sourced from
  - priority fees
  - maximal extractable value (MEV)

Validators earn rewards on the beacon chain (CL) for three key activities [14]:

- Attesting to their view of the beacon chain:
  - voting for a source checkpoint
  - voting for a target checkpoint
  - voting for a chain head block
- Proposing a block
- Sync committee members receive a reward for each slot that they sign off on the correct (from the proposer's point of view) head block.

Validators that report a slashing violation, i.e. an event that triggers a validator to be slashed, receives a reward.

Each active validator will be selected to make one attestation per epoch, consisting of 3 votes: source, target and head votes. In general, the largest part of a validator's rewards, viz. *(84.4%)*: *84.4% = 21.9% (timely source votes) + 40.6% (timely target votes) + 21.9% (timely head votes)* come from making attestations, assuming they are included in a beacon chain block [14].

All reward calculations are based on the 'base reward per increment', where an increment is 1 unit of effective balance = 1 ETH.

$$b = Gwei \left(\frac{EFFECTIVE\_BALANCE\_INCREMENT * BASE\_REWARD\_FACTOR}{\sqrt{total\ \ active\ \ balance\ \ of\ \ current\ \ state}} \right)$$

In the long run, validators can expect to earn $32b$ *Gwei* per epoch if they maintain their effective balance at 32 ETH. Note that as the *total active balance* changes, b changes [14]. When we have auto-compounding of stake, it will also affect the expected rewards. However, simply consolidating validators is not expected to impact on b, since the total active balance will remain unchanged. However, as the number of active validators increase, and consequently the total active balance, the impact on expected earnings becomes greater.

When a validator submits a request to exit, they are expected to still perform their duties until they reach their exit epoch, which is usually approximately 2 epochs later. The waiting time to exit depends on the exit queue which is currently (26 July 2023) empty.

The churn limit is a limit on the entry and exits of validators, and its value depends on the number of active validators. The reason for having a limit on the rate of churn is provide stability in proof of stake (PoS) Ethereum, and it is calculated as follows [14]:.

$$max \left(MIN\_PER\_EPOCH\_CHURN\_LIMIT, \frac{total\ \ number\ \ of\ \ active\ \ validators}{CHURN\_LIMIT\_QUOTIENT} \right),$$
$$where\ \ MIN\_PER\_EPOCH\_CHURN\_LIMIT = 4,$$
$$CHURN\_LIMIT\_QUOTIENT\ \ = 65536$$

Currently this equates to around 10 per epoch, but as the validator set grows, so the churn limit increases [11]. The validator activation queue has been very full since the implementation of withdrawal of stake, and the queue is currently around 80,000 with a wait time of approximate 33 days [4]. There is a dashboard of the validator queue showing the length of the queue and the estimated waiting time for activation [4]. A temporary measure has been proposed to cap the churn limit at 12 to slow down the rate of growth of the validator set. [13].

3.4 Validator yield

The motivation for quantifying yield is twofold: first to observe how this has changed over time, and secondly to use this to inform an intuition of a yield at which there is little or no incentive to stake in Ethereum. When we consider the yield of validators on their staked ETH, it is also worth bearing in mind the associated costs to run and manage a validator. The survey conducted by the EF and EthStaker concluded that the vast majority of solo stakers ((85%) and mini pool operators (78%) who completed the survey specially bought hardware for staking [34]. We contacted some solo stakers for estimates regarding this initial outlay and to estimate ongoing costs. The responses are noted below:
Solo and small stakers
The overheads for running a validator node can be divided into two main categories: initial outlay and ongoing costs. The initial outlay includes purchasing the staking computer and associated items such as routers, uninterruptable power supply (UPS) and networking equipment. The ongoing costs are electricity, additional costs if additional bandwidth is required and not included in the existing internet package for home use, and labour in monitoring the node and keeping it up to date. Based on a small sample of solo stakers, the cost of purchasing a personal computer (PC) to run a validator is approximately \$800 to \$2,000, with optional additional extras such as a high-end router approximately \$500 to \$600, a UPS around \$150 and networking equipment to facilitate high bandwidth around \$1,500. After 3 years it is probably advisable to replace the PC, but not necessarily all the ancillaries. Ongoing costs such as additional electricity usage are minimal and could be as low as \$80 annually.
Staking Pools
Meetings with Infura, Consensys staking and MetaMask (MM) staking were very insightful and the range of infrastructure configurations was discussed as well as the types of staking. MM staking is mainly targeting integration with fractional liquid staking pools and working closely with a fractional staking provider so that users can easily participate in staking via MM. Estimates of costs to validators are more complex, depending on the staking pool and staking pool costs vary too. In general larger staking pools can keep per validator costs reasonably low due to economies of scale.

In conclusion, the overheads for small stakers are probably slightly higher than staking pools, when we work out the average cost per validator, i.e. spinning up and running a 32 ETH validator.

3.5 Validator slashing and penalties

Slashing

The situations that lead to a validator being slashed are few, but they are severe violations of protocol rules that may be considered as a potential solo or coordinated attack on the system. Regardless of the reason for the slashing event, they are all handled in the same way. There is an initial slashing penalty, which is currently set at 1 ETH (or $\frac{1}{32}$ of the stake) and this is followed 18 days after the slashing event by another penalty, known as the correlation penalty.

The purpose of the latter is to penalise what may be a coordinated attack on the chain. Therefore the correlation penalty takes into account slashings 18 days before and after the slashing event.

A validator gets slashed when they are reported and evidence of the violation of the rules is included in a beacon block. For the valid reporting of a slashing event, the reporting validator receives a reward. The intention is that this will help incentivise the reporting of slashable events. Only one proposer slashing can be included in a report, whereas multiple attestation violations can be included in a report. When the slashing is included in a block, the proposer gets a reward which is a fraction of the effective balance of the validator being slashed (currently $\frac{1}{512}$). Up to 16 proposer slashings can be included in a block and up to 2 attester slashing reports. Therefore, if several slashings have occurred, including these reports in a block can generate a generous reward for the proposer.

For more detailed information on slashing and calculations, please refer to the latest version of Edgington's *Upgrading Ethereum* book [14] which incorporates the updates included in the Capella hard fork. In summary the events that lead to slashing are:

1. "making two differing attestations for the same target checkpoint"
2. "making an attestation whose source and target votes 'surround' those in another attestation from the same validator.
3. "proposing more than one distinct block at the same height"
4. "attesting to different head blocks, with the same source and target checkpoints"

The first two relate to Casper Friendly finality gadget (FFG) consensus, and the latter two are related to Latest message driven (LMD) Greedy Heaviest-Observed Sub-Tree (GHOST) consensus.

Edgington points out that 'slashable behaviours relate to "equivocation", which is when a validator contradicts something it previously advertised to the network'. Hence it is important for validators to ensure that they do not 'accidentally' equivocate. This could theoretically happen as a result of bugs in client software, but the vast majority of slashings have been due to node operators running two different nodes using the same validator keys. The reason may have been to improve uptime, but the risk of slashing is too great compared to any potential benefit in uptime [14]. There was also an incident where a validator exploited a vulnerability in a relay operator running mev-boost, an open source proposer-builder separation protocol. Flashbots posted a detailed post-mortem of the event.

Apart from the slashing penalties, a slashed validator accrues attestation penalties until such time as they exit, which is not until 2^{13} $epochs = 8,192$ $epochs \approx 36$ $days$ after being slashed. Moreover, if there is an inactivity leak at the time, the penalties imposed on slashed validators will be higher. Slashed validators cannot earn any attestation rewards while waiting to exit. It seems rather odd, but a slashed validator can still be elected to be the proposer for the next block. However, their block will be deemed to be invalid. The only duty for which they could receive a small reward is if they are selected to be in the sync committee, but the probability of this happening is very small.

Penalties

Slashing is the most severe penalty a validator is subjected to and as explained they can accrue several extra penalties while they wait to exit. However, there are a number of smaller, less serious 'misdemeanours', or failure to perform their duties that can result in penalties for validators. The validator's stake is reduced by the penalty and the ETH is burnt, thereby reducing

net issuance [14].

Attestation penalties

- Missed source and target votes (i.e. missed Casper FFG votes), but no penalty for a missed head vote.
- Incorrect source vote, then target vote is missed.
- Incorrect source or target vote, then head vote is missed.

Sync committee penalties

- Non-participation of a member incurs a penalty equivalent to the reward they would have received if it was correct

3.6 Staked ETH as a percentage of ETH supply over time

Visualising the percentage of total ETH that is tied up in staking would be interesting to observe, especially as it has changed over time.

There are also crypto analytical companies such as Parsec that report on liquid staking derivatives. The analytics provided by Parsec are captured in figures 184 - 189 on pages 126 - 129.

According to the Staking Launchpad on June 2023:

- Total ETH staked: 19,357,605 ETH
- Total validators: 606,947
- Current annual percentage rate (APR): 4.74%

3.7 Griefing/discouragement attacks

According to Buterin a griefing attack is when a validator acts maliciously inside a consensus mechanism to reduce other validators' revenue even at some cost to themselves to encourage the victims to drop out of the mechanism [8].

The two main motivations for reducing the number of participants are most likely because fewer participants:

- mean greater rewards for those remaining in the mechanism
- helps to prepare an attack on the chain by reducing the cost of an attack

Some strategies have already been put in place to avoid discouragement attacks [14]:

- inverse square root scaling of validator rewards
- scaling of rewards with participation (viz. for each "source, target, and head vote, the attester's reward is scaled by the proportion of the total stake that made the same vote")
- zeroing attestation rewards during an inactivity leak
- rate limiting of validator exists, which means that an attacker needs to sustain an attack for longer and at greater cost in order to achieve the same outcome.

3.8 Centralisation forces

Centralisation needs to be assessed within the context of this grant and the proposed increase in maximum effective balance, especially with respect to large stakers and staking pools.

3.9 Health of the Ethereum ecosystem

Ether alpha combines various aspects of the ecosystem to give an overall impression of the health of the network. They pull information from various sources for 'Project Sunshine' dashboard [3].

Historic and current trends for stake concentration are important to observe as these are warning signs that the chain is becoming more vulnerable to collusion. The consolidation of stake through EIP 7251 (currently in draft form) [29] is unlikely to change the dynamics of stake concentration, since it is encouraging consolidation of validators already being operated by stakers. However, with more node operators and validators joining larger staking pools staked ETH will become more one-sided in favour of staking pools.

The Rated network also provides detailed metrics and visualisations to gauge the health of the network [28].

4 Data Sources

4.1 Key data points and parameters

- The beacon chain **deposit contract address** is: 0x00000000219ab540356cBB839Cbe05303d7705Fa
- The beacon chain **genesis block number** is 11182202

The dynamic rate limit of validator activations and exits per epoch need to be taken into account when validators are combined into larger validators. Moreover, there is another mechanism in place which bypasses the entry and exit rate limiting, viz. top-ups. Validators currently top their stake up when it drops below 32 ETH so that they maximise their rewards without having to go into the queue. Clearly these are smaller amounts of ETH since if a validator's effective balance falls below 16 ETH they are automatically exited by the protocol, hence the maximum amount of a top-up is 16 ETH.

4.2 Key Parameters

Rocket Pool has a simple explanation of the various validator rewards and a table which summarises the expected rewards when staking: A Node Operator's Responsibilities.

Genesis settings

Name	Value
`MIN_GENESIS_ACTIVE_VALIDATOR_COUNT`	`uint64(2**14)` (= 16,384)
`MIN_GENESIS_TIME`	`uint64(1606824000)` (Dec 1, 2020, 12pm UTC)
`GENESIS_FORK_VERSION`	`Version('0x00000000')`
`GENESIS_DELAY`	`uint64(604800)` (7 days)

Time parameters

Name	Value	Unit	Duration
`SECONDS_PER_SLOT`	`uint64(12)`	seconds	12 seconds
`SECONDS_PER_ETH1_BLOCK`	`uint64(14)`	seconds	14 seconds
`MIN_VALIDATOR_WITHDRAWABILITY_DELAY`	`uint64(2**8)` (= 256)	epochs	~27 hours
`SHARD_COMMITTEE_PERIOD`	`uint64(2**8)` (= 256)	epochs	~27 hours
`ETH1_FOLLOW_DISTANCE`	`uint64(2**11)` (= 2,048)	Eth1 blocks	~8 hours

Validator cycle

Name	Value
`EJECTION_BALANCE`	`Gwei(2**4 * 10**9)` (= 16,000,000,000)
`MIN_PER_EPOCH_CHURN_LIMIT`	`uint64(2**2)` (= 4)
`CHURN_LIMIT_QUOTIENT`	`uint64(2**16)` (= 65,536)

Figure 3: Configuration settings

Misc

Name	Value
`GENESIS_SLOT`	`Slot(0)`
`GENESIS_EPOCH`	`Epoch(0)`
`FAR_FUTURE_EPOCH`	`Epoch(2**64 - 1)`
`BASE_REWARDS_PER_EPOCH`	`uint64(4)`
`DEPOSIT_CONTRACT_TREE_DEPTH`	`uint64(2**5)` (= 32)
`JUSTIFICATION_BITS_LENGTH`	`uint64(4)`
`ENDIANNESS`	`'little'`

Figure 4: Miscellaneous key constant values

Misc

Name	Value
`MAX_COMMITTEES_PER_SLOT`	`uint64(2**6)` (= 64)
`TARGET_COMMITTEE_SIZE`	`uint64(2**7)` (= 128)
`MAX_VALIDATORS_PER_COMMITTEE`	`uint64(2**11)` (= 2,048)
`SHUFFLE_ROUND_COUNT`	`uint64(90)`
`HYSTERESIS_QUOTIENT`	`uint64(4)`
`HYSTERESIS_DOWNWARD_MULTIPLIER`	`uint64(1)`
`HYSTERESIS_UPWARD_MULTIPLIER`	`uint64(5)`

- For the safety of committees, `TARGET_COMMITTEE_SIZE` exceeds the recommended minimum committee size of 111; with sufficient active validators (at least `SLOTS_PER_EPOCH * TARGET_COMMITTEE_SIZE`), the shuffling algorithm ensures committee sizes of at least `TARGET_COMMITTEE_SIZE`. (Unbiasable randomness with a Verifiable Delay Function (VDF) will improve committee robustness and lower the safe minimum committee size.)

Gwei values

Name	Value
`MIN_DEPOSIT_AMOUNT`	`Gwei(2**0 * 10**9)` (= 1,000,000,000)
`MAX_EFFECTIVE_BALANCE`	`Gwei(2**5 * 10**9)` (= 32,000,000,000)
`EFFECTIVE_BALANCE_INCREMENT`	`Gwei(2**0 * 10**9)` (= 1,000,000,000)

Time parameters

Name	Value	Unit	Duration
`MIN_ATTESTATION_INCLUSION_DELAY`	`uint64(2**0)` (= 1)	slots	12 seconds
`SLOTS_PER_EPOCH`	`uint64(2**5)` (= 32)	slots	6.4 minutes
`MIN_SEED_LOOKAHEAD`	`uint64(2**0)` (= 1)	epochs	6.4 minutes
`MAX_SEED_LOOKAHEAD`	`uint64(2**2)` (= 4)	epochs	25.6 minutes
`MIN_EPOCHS_TO_INACTIVITY_PENALTY`	`uint64(2**2)` (= 4)	epochs	25.6 minutes
`EPOCHS_PER_ETH1_VOTING_PERIOD`	`uint64(2**6)` (= 64)	epochs	~6.8 hours
`SLOTS_PER_HISTORICAL_ROOT`	`uint64(2**13)` (= 8,192)	slots	~27 hours

Figure 5: Parameters for committees and time

Rewards and penalties

Name	Value
`BASE_REWARD_FACTOR`	`uint64(2**6)` (= 64)
`WHISTLEBLOWER_REWARD_QUOTIENT`	`uint64(2**9)` (= 512)
`PROPOSER_REWARD_QUOTIENT`	`uint64(2**3)` (= 8)
`INACTIVITY_PENALTY_QUOTIENT`	`uint64(2**26)` (= 67,108,864)
`MIN_SLASHING_PENALTY_QUOTIENT`	`uint64(2**7)` (= 128)
`PROPORTIONAL_SLASHING_MULTIPLIER`	`uint64(1)`

- The `INACTIVITY_PENALTY_QUOTIENT` equals `INVERSE_SQRT_E_DROP_TIME**2` where `INVERSE_SQRT_E_DROP_TIME := 2**13` epochs (about 36 days) is the time it takes the inactivity penalty to reduce the balance of non-participating validators to about `1/sqrt(e) ~= 60.6%`. Indeed, the balance retained by offline validators after `n` epochs is about `(1 - 1/INACTIVITY_PENALTY_QUOTIENT)**(n**2/2)`; so after `INVERSE_SQRT_E_DROP_TIME` epochs, it is roughly `(1 - 1/INACTIVITY_PENALTY_QUOTIENT)**(INACTIVITY_PENALTY_QUOTIENT/2) ~= 1/sqrt(e)`. Note this value will be upgraded to `2**24` after Phase 0 mainnet stabilizes to provide a faster recovery in the event of an inactivity leak.
- The `PROPORTIONAL_SLASHING_MULTIPLIER` is set to `1` at initial mainnet launch, resulting in one-third of the minimum accountable safety margin in the event of a finality attack. After Phase 0 mainnet stabilizes, this value will be upgraded to `3` to provide the maximal minimum accountable safety margin.

Max operations per block

Name	Value
`MAX_PROPOSER_SLASHINGS`	`2**4` (= 16)
`MAX_ATTESTER_SLASHINGS`	`2**1` (= 2)
`MAX_ATTESTATIONS`	`2**7` (= 128)
`MAX_DEPOSITS`	`2**4` (= 16)
`MAX_VOLUNTARY_EXITS`	`2**4` (= 16)

Figure 6: Parameters for rewards and penalties, and operations

4.3 Total ETH Supply

The total supply of ETH is reasonably complicated to compute for two main reasons: implementation of EIP-1559 and the Merge. Currently we are "(a) burning ETH via the base fee and (b) the issuance is variable depending on the number of validators." [14].

- Ultrasound is considered a credible source for total ETH supply projections.
  Ultra sound money visualises various aspects of Ether supply since the Merge, gas, supply projections, the burn, total value secured - TVS and monetary premium. See figures 13 - 21, on pages 21 - 24.

  – Ultrasound supplied two datasets for our analysis - the first had total supply at a more accurate and finer grained level, but shorter time period and the second dataset had data points roughly every 1,000 epochs covering from soon after Beacon chain genesis. The latter dataset is from Glassnode and would not be as accurate as the initial data provided by Alex Tesfamichael from Ultrasound.

- *Etherscan* is a good source of historic data for the growth in Ether supply since 2015. There are several pages of detailed information and the *Charts & Statistics* webpage has several visualisations, often with the ability to select different time ranges and a link to download the raw data as csv files, providing that Etherscan is acknowledged when these datasets are used.
  Figures 36 to 48 on pages 37 to 43 show the visualisations that are currently available.

4.4 Validators, Stakers and Staking pools

LIDO

LIDO is a popular liquid staking pool. At the time of writing, 7 June 2023, the total amount of ETH staked with LIDO is 7,127,430 ETH.

Several graphs have been generated in Dune Analytics. See Figures 81 to 83 on pages 64 to 65.

Moreover Hex provides interesting visualisations of various Lido metrics of node operators and validators such as location of servers, client diversity, stake distribution equality metrics and jurisdictional dispersion [21].

Rocket Pool

A Rocket Pool node only needs to stake 16 ETH, and this stake is then coupled with 16 ETH from the staking pool to create a validator, known as a "minipool". Staking in the Rocket Pool can be a stake of a little as 0.01 ETH, which is then issued as an rETH token representing the amount deposited into the pool. A node operator would obtain staked ETH from the pool to form a validator.

There is documentation at the Rocket Pool website that clearly explains Ethereum staking and how it works when staking with Rocket Pool.

Currently, 8 June 2023, Rocket Pool has staked 722,176 ETH and has 2,842 node operators.

If we can identify the number of distinct rETH token holders, we would be able to determine the number of stakers staking ETH in Rocket Pool. Examples of the graphs and information available from the Dune dashboard are shown in figures 84 - 96 on pages 66 - 72.

Data from an archive node

Accessing a teku-besu archive node, `teku-besu-ohio-mainnet-archive-01`, we were able to use several API endpints to extract some rich data for validators.
We selected several API endpoints from those listed in GitHub: Eth Beacon Node API
Some visualisations of validator information from the archive node are in figures 190 - 194, pages 131 - 135.

Rated network explorer

Rated provides documentation for context and detail of the metrics and visualisations presented on its website. The home page displays Beacon Chain validator ratings for the Ethereum beacon chain, figure 22, page 25, but one can also select the Göerli test network to display ratings for those validators. Figure 29, page 31 depicts four metrics to reflect network health and four reference rates of return for the entire active validator set.

4.5 Client and staking pool diversity

- *Diversify Now* [2] dashboard by *Ether alpha* displays the current client distribution in the Consensus and Execution layers. (Figure 7, page 18).
- *Beacon Chain Network Public Dashboard* by *Miga Labs* has several visualisations:
  - Client diversity (Figure 8(a), page 19)
  - Client diversity evolution (Beacon chain client distribution over time) (Figure 8(b), page 19)
  - OS distribution of active nodes (Figure 9(a), page 19)
  - Geographical representation of client evolution over time (Figure 9(b), page 19)
  - Active nodes round trip time distribution (RTT) (Figure 10(a), page 20)
  - Graphical distribution (Beacon chain node distribution) (Figure 10(b), page 20)
  - RTT distribution (Figure 11(a), page 20)
  - Advertised attestation subnets subscription (Figure 11(b), page 20)
  - Number of beach nodes per IP (Figure 12), page 20)

  However, it is important to note that it is challenging to measure peer types in the network, and therefore the figures are at best approximations based on the information at hand.

4.6 Multiple datasets

There are several resources that contain lists and visualisations of a variety of data from Ethereum Mainnet. Obtaining the raw data used on the websites and dashboards are not always easily accessible.

- *beaconcha.in*, an open source Ethereum explorer, is a rich and informative resource providing visualisations and summary statistics of various aspects of the chain. It is not clear if it is possible to gain access to the data used to generate the many graphs and summary statistics. The website currently contains the following:
  - On the home page, there is a **progress line** at the top of the page showing the *number of slots left in the current epoch.* (Figure 99, page 75)

- Immediately below the progress line, there is a **summary line** showing the *current epoch number*, the *last finalised epoch*, the *current slot number*, the *number of active and pending validators*, the *total staked ETH* and the *average validator balance*. (Figure 99)
- Below this summary there is a **graph** of the *number of active validators* and *staked ETH* for the last week (Figure 99)
- Then there are two side by side tables. The **left table** has information about the most recent epochs: *epoch number, time, whether it is final, the eligible ETH, the number of percentage of votes*. The **right table** has information about the most recent blocks: *epoch number, slot number, block number, status of the block (proposed or missed), time* and the *proposer id*. These two tables are shown in Figure 100, page 75).
- Moreover, one can click on the epoch, slot and block numbers in the tables to obtain a detailed view of the epoch, slot or block number.
- There is also a link to the validator ID in the right table that provides a detailed view of that validator.
- Figures 101 - 105 on pages 76 - 78 displays detailed blockchain data.
- Figures 106 - 115 on pages 79 - 83 displays detailed validator data.
- Beaconcha.in provide additional visualisations and tools. For example, the ability to generate graphs to show the correlation between two variables (Figure 117 on page 84.

- *Mevboost.pics*
  - *MEV-Boost General Dashboard*
    Examples of the contents displayed on the general dashboard can be seen in figures 134 - 137 on pages 91 - 94.
  - *MEV-Boost Builders Dashboard*
    Examples of the contents displayed on the builders dashboard can be seen in figures 142 - 145 on pages 99 - 102.
  - *MEV-Boost Relays Dashboard*
    Examples of the contents displayed on the relays dashboard can be seen in figures 138 - 141 on pages 95 - 98.
  - *MEV-Boost Validators Dashboard*
    Examples of the contents displayed on the validators dashboard can be seen in figures 146 - 149 on pages 103 - 106.
  - *Mevboost.pics - Open Data* will eventually provide links to download several datasets: (Figure 150, page 107)
    * *eth_data* - Slots since Merge with additional MEV-Boost and validator info such as: date, slot, block number, relay, builder pubkey, proposer pubkey, mevboost value, builder, validator *(Available now)*
    * *pubkey_mapping* - Validator public keys mapped to known entities such as Lido, Kraken ect. *(Available now)*
    * *tc_txs* - Tornado Cash related transactions *(Not available)*
    * *staking_txs* - Deposit transactions to the ETH2 Deposit contract *(Not available)*
    * *relays_over_time* - Number of successfully relayed blocks per day *(Not available)*

    * *builders_over_time* - Number of successfully built blocks per day *(Not available)*

- *Metrika*
  The various dashboards available from Metrika are sponsored by the Ethereum Foundation. One can enter a withdrawal address in the search field on the homepage to retrieve withdrawal information for the time range selected, which is either 1 day, 1 week or 2 weeks. See figure 151 on page108. Following this there are several charts and tables covering the network, consensus, withdrawals and validators. Screen shots of the additional visualisations and tables are shown in figures 152 - 156 on pages 108 - 110.

- *Nansen*
  Nansen provides some dashboards and visualisations that are freely available, but they also provide a paid service to customers for additional information, metrics and visualisations. Two dashboards are of interest to this project:

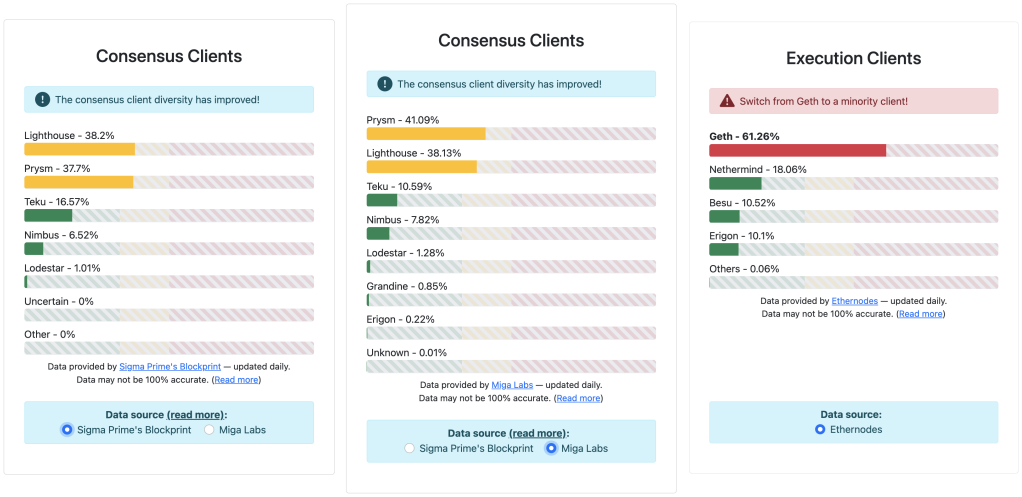
  – Dashboard displaying key metrics of the Shapella upgrade when withdrawals were activated (figure 157 - 164 on pages 111 - 115) [26]

  – Eth2 dashboard - overview of total ETH deposited, unique depositors, unique validators, proposer and attestor metrics (figure vv - zz on pages vv-zz) [25]

- *BeaconScan: The Official Etherscan Beacon Chain Ethereum 2.0 Explorer*
  The BeaconScan website is a product of EtherScan and provides multiple views of data on the beacon chain. Figures 165 - 183 on pages 116 - 125 demonstrate the type of information and visualisations that are freely available [19].

4.7 Existing visualisations

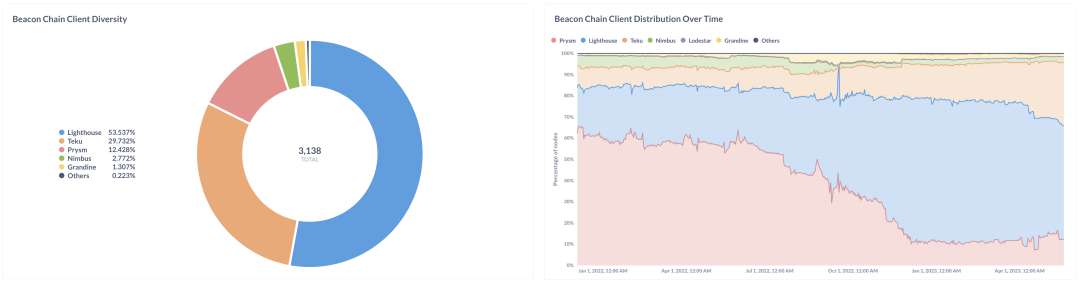
Diversify Now



(a) (b) (c)

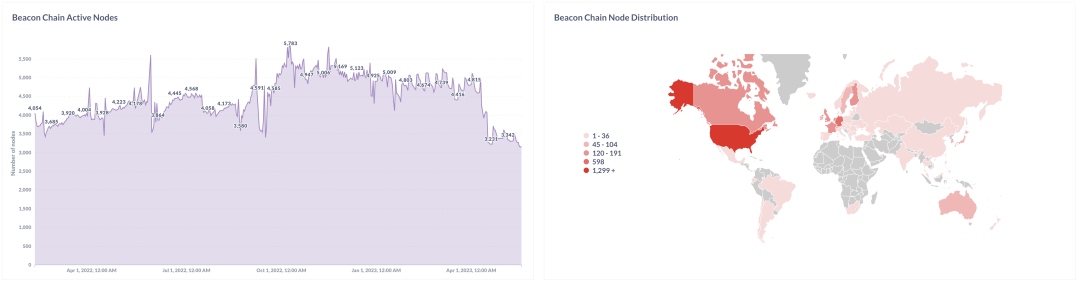
Figure 7: Consensus layer client diversity using Sigma Prime's Blockprint data (a) and using Migalabs data (b). Execution layer client diversity using Ethernodes data (19 May 2023)

Migalabs



(a) (b)

Figure 8: Beacon chain client diversity from Migalabs (a) and client distribution over time (b) (9 May 2023)

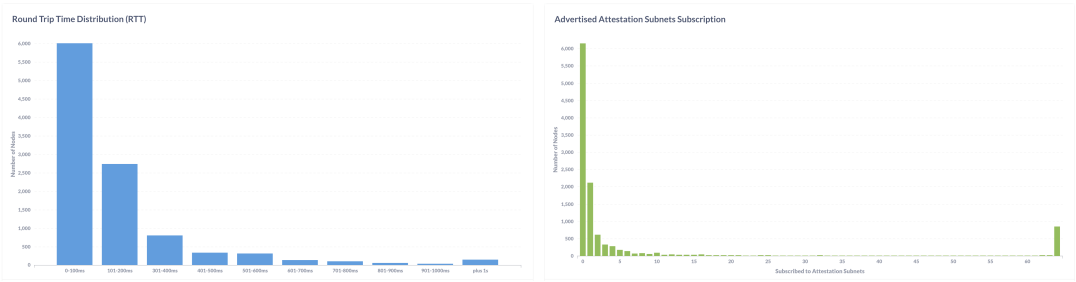


(a) (b)

Figure 9: Operating system distribution of active beacon chain nodes from Migalabs (a) and client diversity evolution of beacon chain nodes (b) (9 May 2023)

(a) (b)

Figure 10: Distribution of active beacon chain nodes round trip time (RTT) from Migalabs (a) and geographical distribution (b) (9 May 2023)



(a) (b)

Figure 11: Distribution of active beacon chain nodes round trip time distribution (RTT) from Migalabs (a) and advertised attestation subnets subscription (b) (9 May 2023)

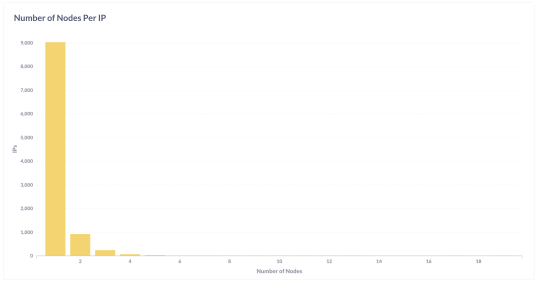


Figure 12: Number of beacon nodes per IP from Migalabs

Ultrasound money

Figure 13: ETH supply over time, current supply and change, 22 May 2023

Figure 14: Burn, supply growth, and issuance, 22 May 2023

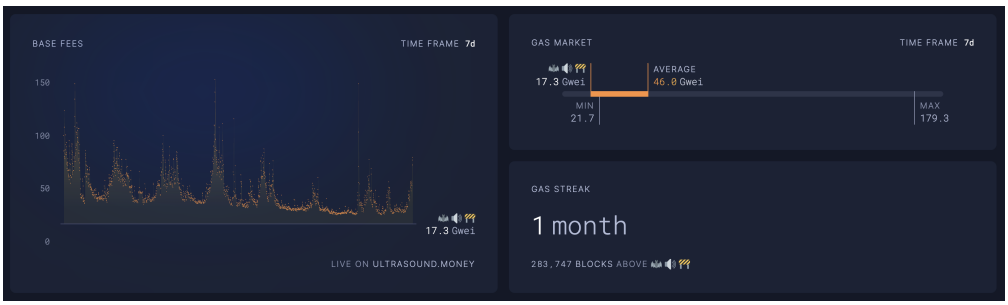


Figure 15: Gas market, 22 May 2023

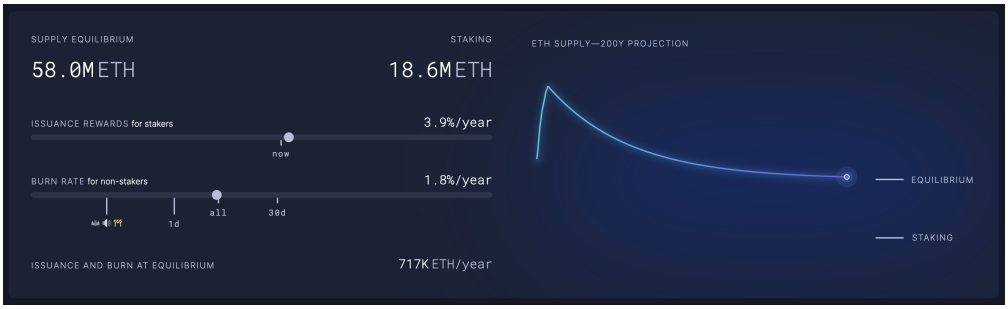


Figure 16: Interactive ETH supply projections - sliders provided for issuance rewards and burn rate , 22 May 2023

Figure 17: 2YETH supply projection, 22 May 2023

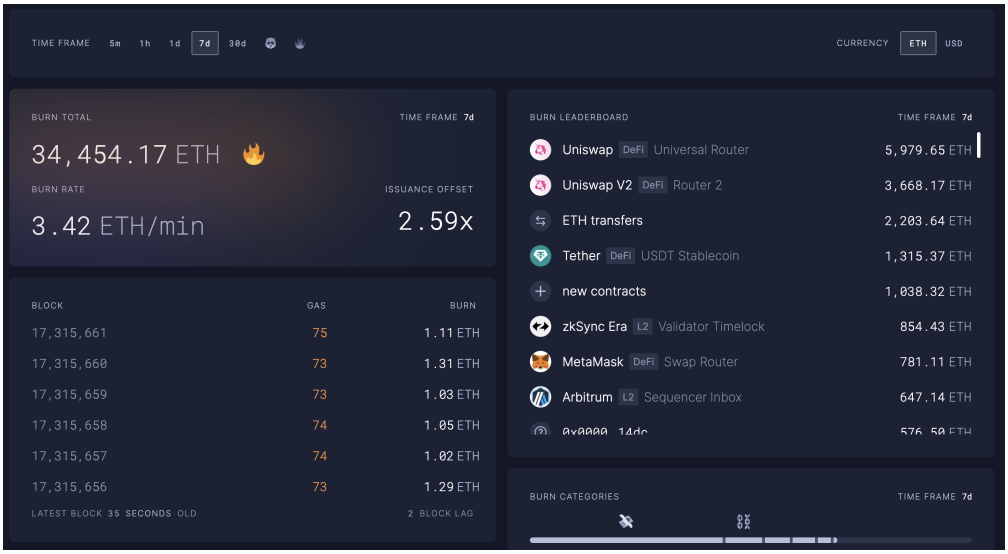


Figure 18: Total burn and rate for selected time interval; latest block gas and burn leaderboard, 22 May 2023

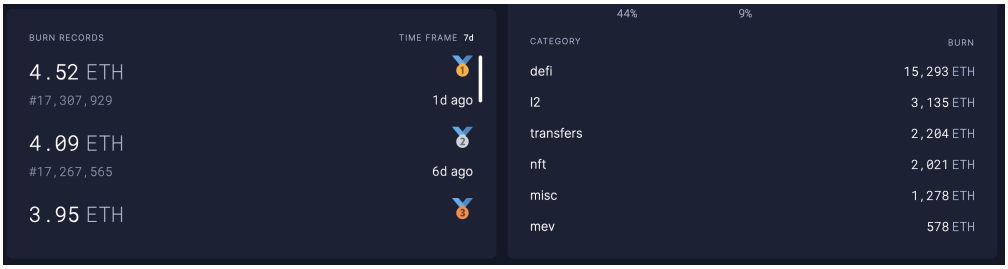


Figure 19: Burn records (top 3) and top 5 categories for most ETH burnt, 22 May 2023

Figure 20: Statistics for total value secured (TVS), including NFT and ERC20 leaderboards, 22 May 2023

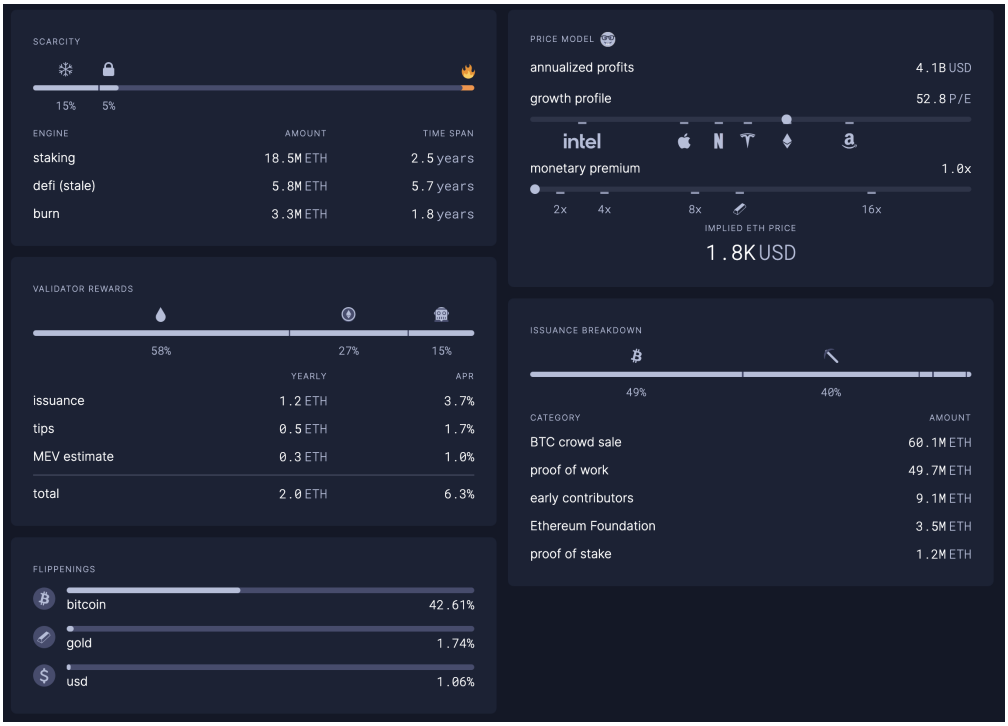


Figure 21: Monetary premium shows Scarcity (staking, defi, burn), Validator rewards (issuance, tips, mev, Flippenings (bitcoin, gold and usd), Issuance breakdown by category and an interactive price model based on selected growth profile and monetary premium, 22 May 2023

Rated network explorer

Entity Views

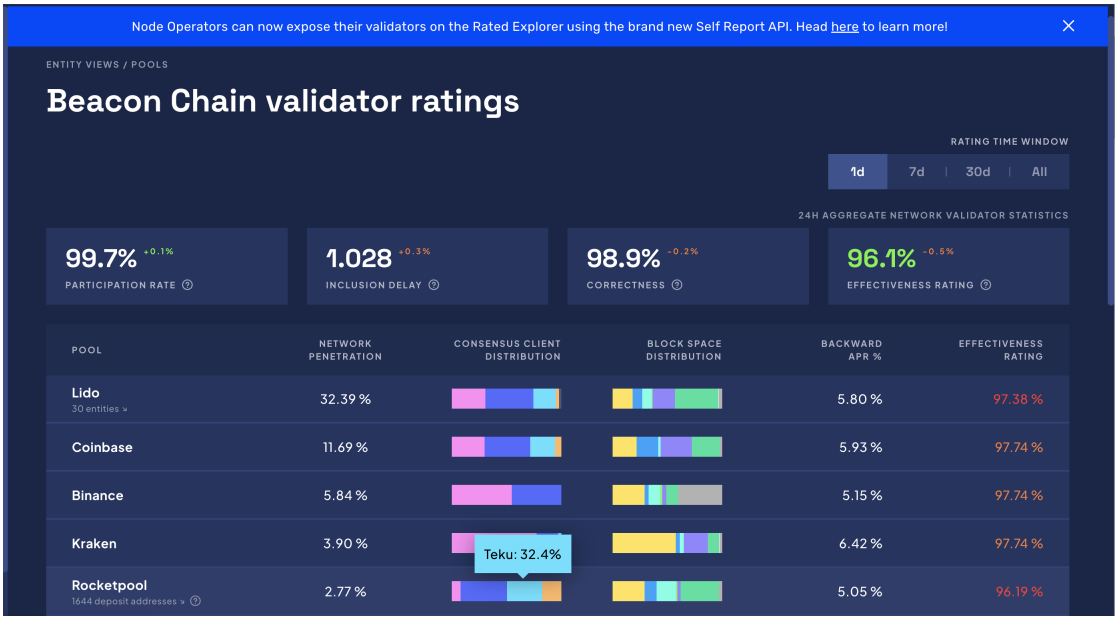


Figure 22: Rated network explorer: beacon chain validator ratings for staking pools. Select from timeframes: 1 day, 7 days, 30 days, or all (since merge) , 1 June 2023

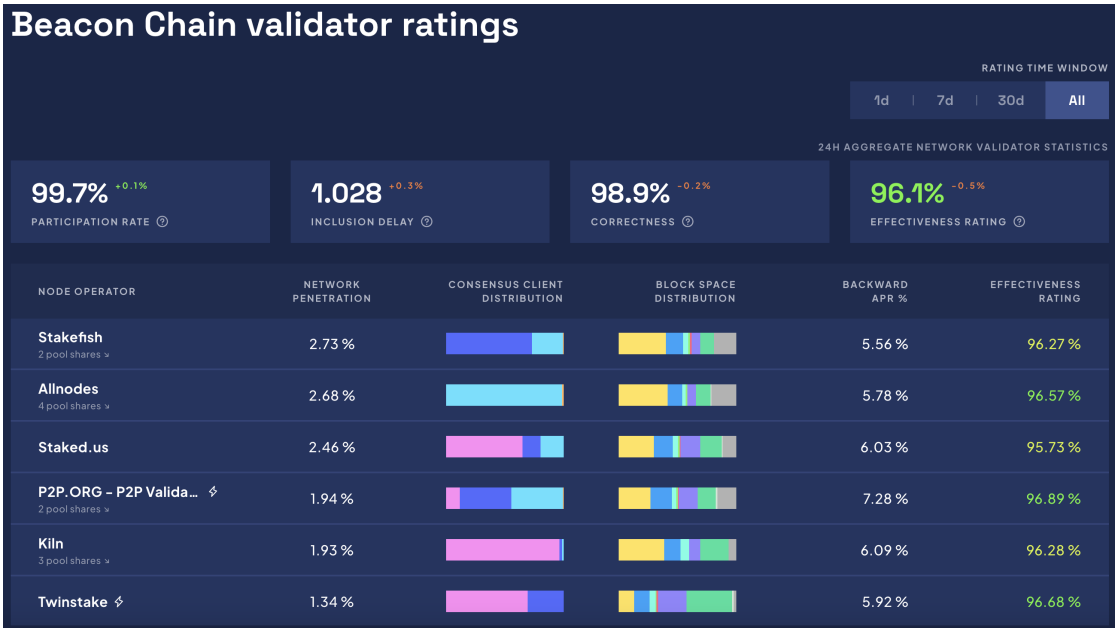


Figure 23: Rated network explorer: beacon chain validator ratings for node operators. Select from timeframes: 1 day, 7 days, 30 days, or all (since merge) , 1 June 2023

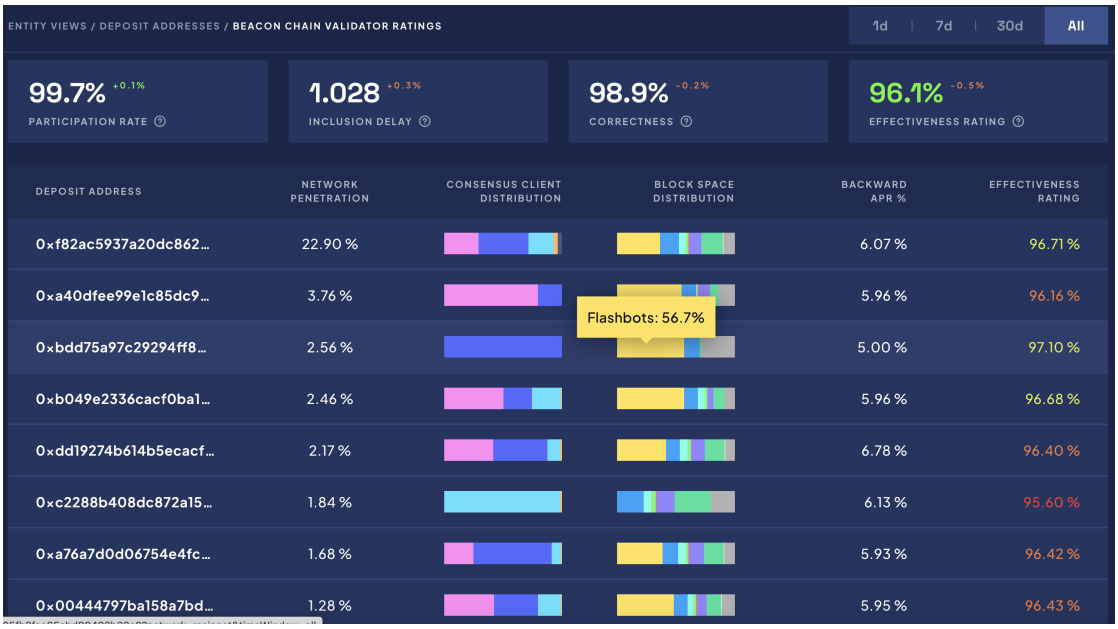
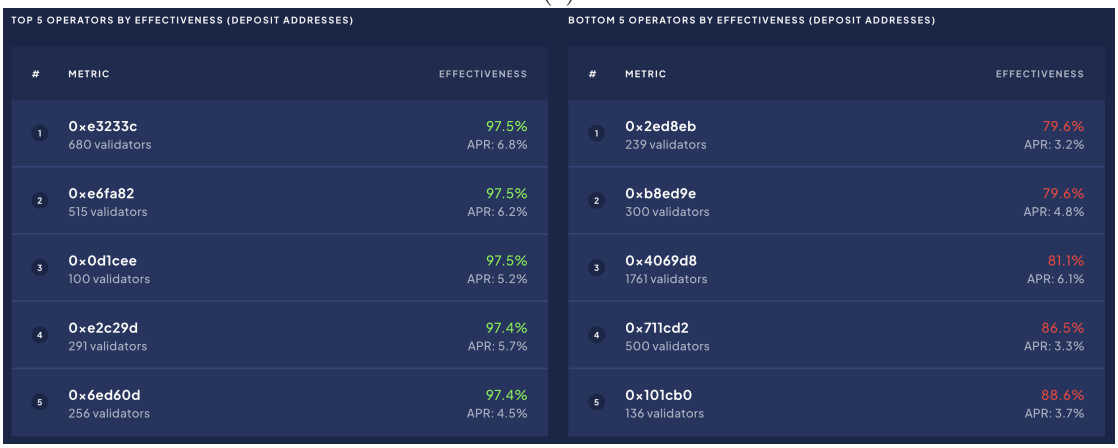


Figure 24: Rated network explorer: beacon chain validator ratings by deposit addresses. Select from timeframes: 1 day, 7 days, 30 days, or all (since merge) , 1 June 2023

Figure 25: Rated network explorer: view of a chosen validator (using id or public key). Select from timeframes: 1 day, 7 days, 30 days, or all (since merge) , 1 June 2023

Aggregate Views

(a)



(b)

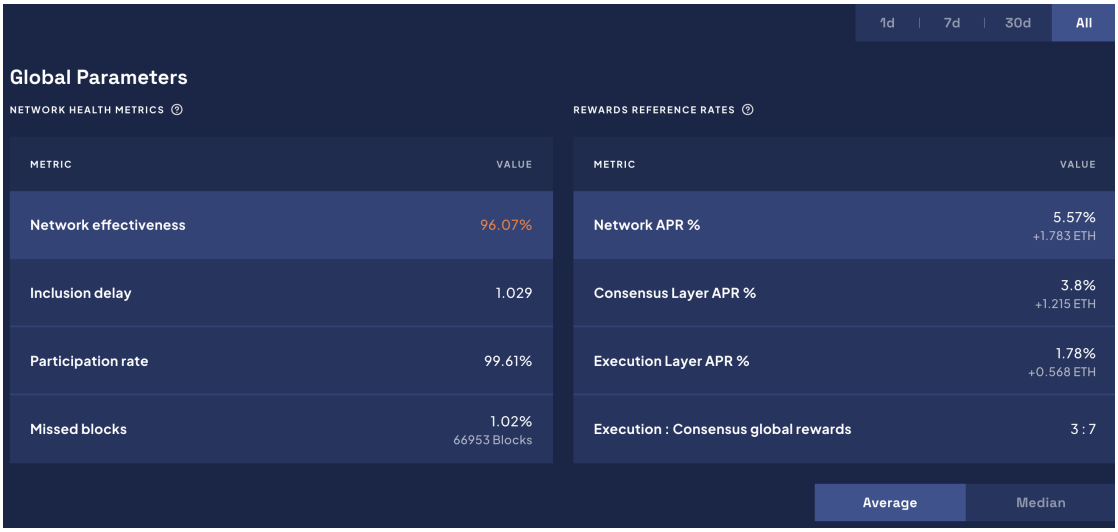
Figure 26: Rated network explorer: top 5 and bottom 5 identified operators (a) and the top and bottom 5 operators by deposit addresses (b). Timeframes: 1 day, 7 days, 30 days or all (since merge), 1 June 2023

(a)

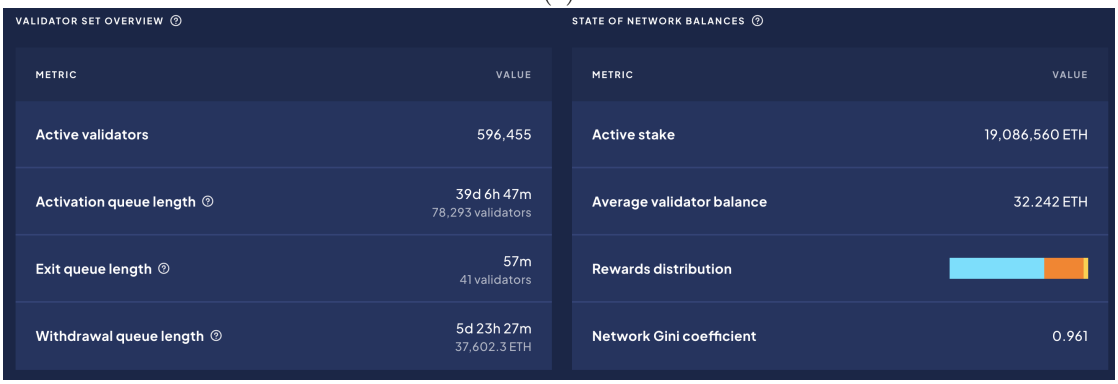
(b)

Figure 27: Rated network explorer: top 5 and bottom 5 validators (a). Top 5 and bottom 5 of operators that facilitated some MEV (total or average) (b), For both visualisations, select a timeframe: 1 day, 7 days, 30 days or all (since merge),1 June 2023

Figure 28: Rated network explorer: top 5 entities by times slashed and top 5 operators by number of slashes reported. Select timeframes of 30 days, or all days (since merge) , 1 June 2023

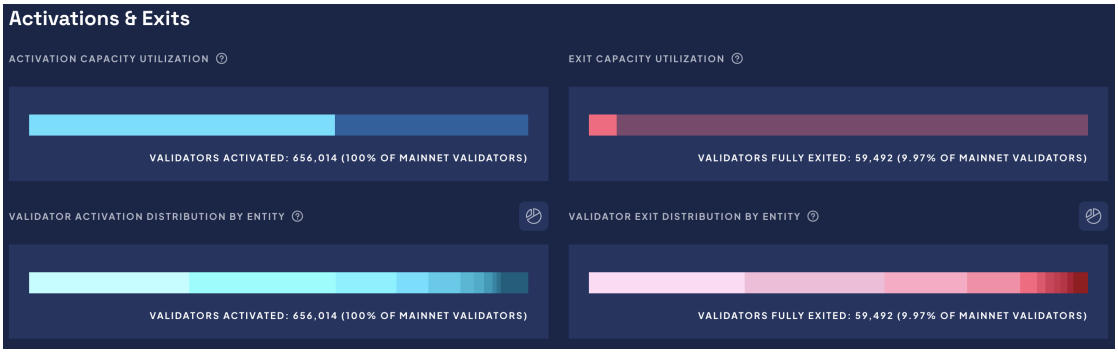


(a)

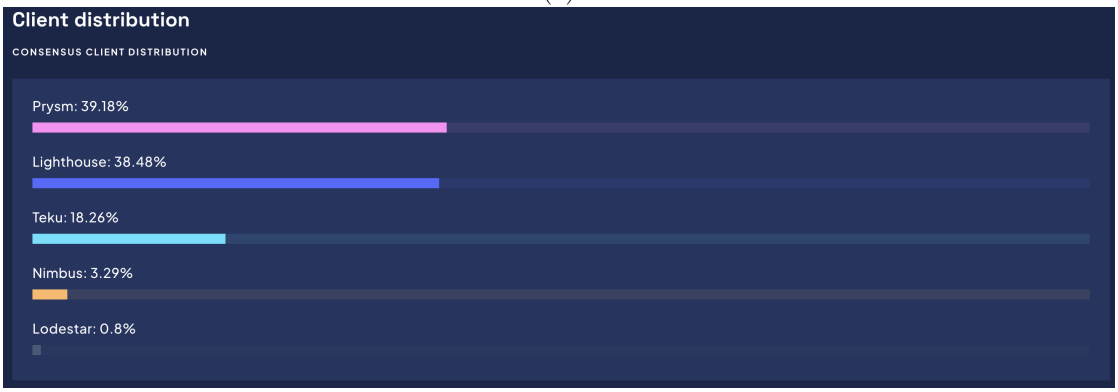


(b)

Figure 29: Rated network explorer: high level metrics to reflect the health of the network (a) and four reference rates of return for the entire active validator set. (b), For both visualisations, select a timeframe: 1 day, 7 days, 30 days or all (since merge),1 June 2023



(a)



(b)

Figure 30: Rated network explorer: activation & exits information: the number of validators activated and the proportion of activation capacity for selected timeframe, and similarly for validators exiting. (a) and four reference rates of return for the entire active validator set. (b), For both visualisations, select a timeframe: 1 day, 7 days, 30 days or all (since merge),1 June 2023

MEV Relay Landscape

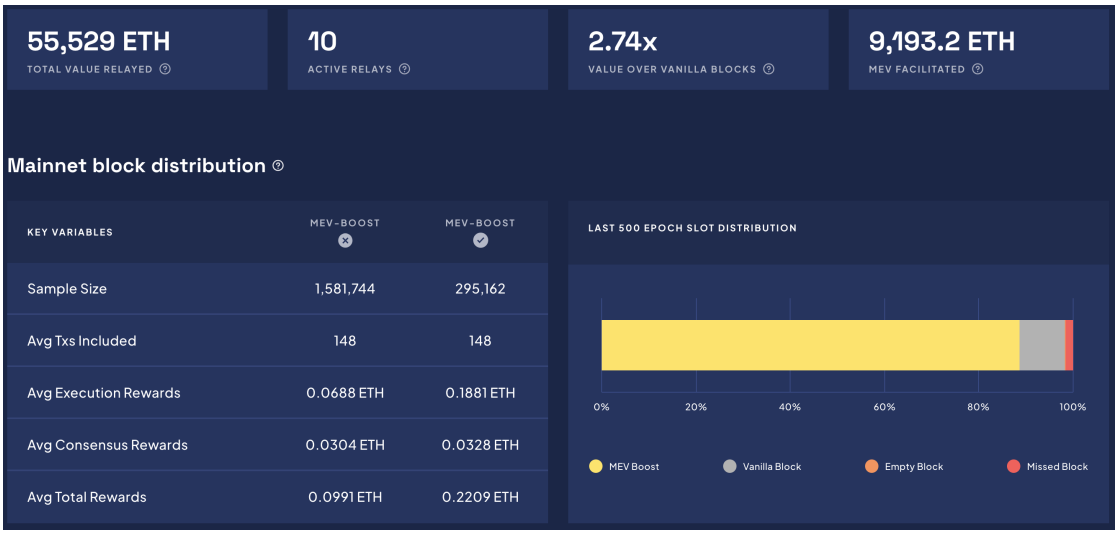


Figure 31: Rated network explorer: MEV relay summary statistics for 30 days, selected from timeframes: 1 day, 7 days, 30 days or all (since merge), 6 June 2023

MEV RELAYS	SAMPLE SIZE	AVG TXS INCLUDED	MEDIAN BASELINE MEV (IN ETH)	MEDIAN PRIO FEES (IN ETH)	MEDIAN EXECUTION REWARDS (IN ETH)
Ultra Sound Money	122,633	141	0	0.0855	0.0977
Flashbots	92,852	138	0	0.0782	0.0899
Agnostic	79,460	141	0	0.0828	0.0945
Bloxroute (maxprofit)	29,764	143	0	0.0827	0.0943
Blocknative	17,808	149	0	0.0931	0.1041
Bloxroute (regulated)	4,336	149	0	0.0935	0.1038
Aestus	3,174	147	0	0.1189	0.1342
Eden Network	1,970	106	0	0.1078	0.1215
Manifold	637	129	0	0.0608	0.0669
Bloxroute (ethical)	380	129	0	0.0338	0.0371

Figure 32: Rated network explorer: Comparison between MEV relays for blocks procured from relays that were included in the canonical chain for all days, selected from timeframes: 1 day, 7 days, 30 days or all (since merge), 6 June 2023

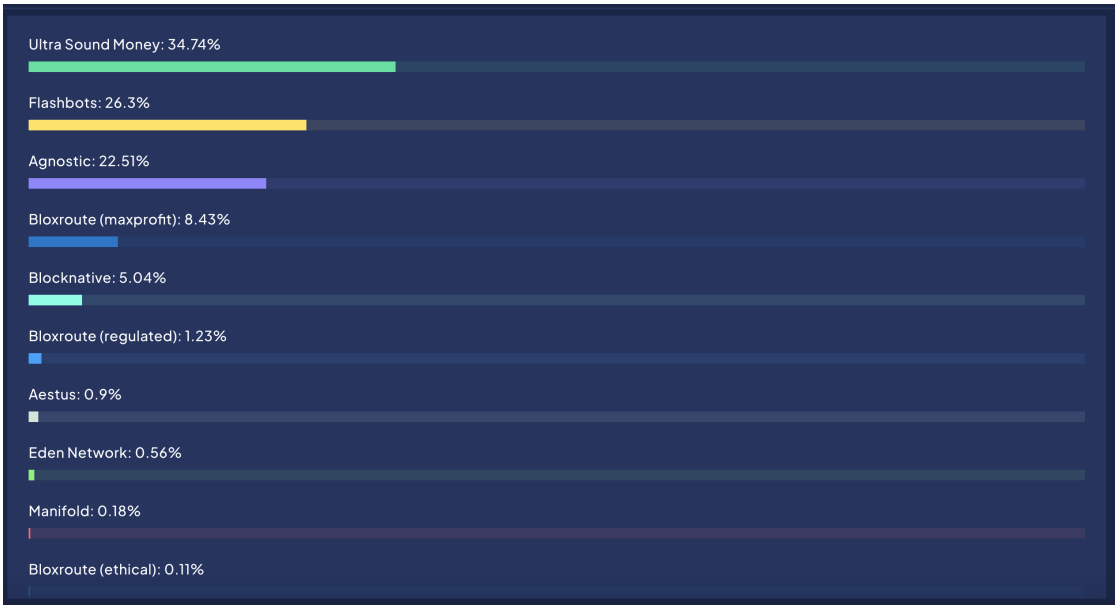


Figure 33: Rated network explorer: MEV-boost relay market share selecting all days from timeframes: 1 day, 7 days, 30 days or all (since merge), 6 June 2023

MEV Builder Landscape

Figure 34: Rated network explorer: MEV relay summary statistics for 30 days, selected from timeframes: 1 day, 7 days, 30 days or all (since merge), 6 June 2023

Diversified Staked ETH Index (dsETH) from Index Coop

Figure 35: Rated network explorer: Key metrics of staked ETH index and time series for all available days, selected from timeframes: 1 day, 7 days, 30 days or all (since merge), 6 June 2023

Etherscan

There are several webpages with detailed information on transactions, blocks, accounts and tokens. In the screenshots below, figures 37- 44 on pages 37- 41), are a few extracts from the detailed information on Etherscan and the data visualisations provided by them. Many of the dashboards allow the user to interact with the data being displayed by entering specific validators, blocks etc, that are of interest, or selecting one of the different time periods available.

Moreover, there are several summary graphs and visualisations that have been created and are displayed in the *Charts & Statistics* section of the website. These visualisations are shown in figures 45- 73 on pages 42 - 58. There is some degree of interactivity in these charts and diagrams, which includes the ability to zoom in on a section of a graph in several instances.

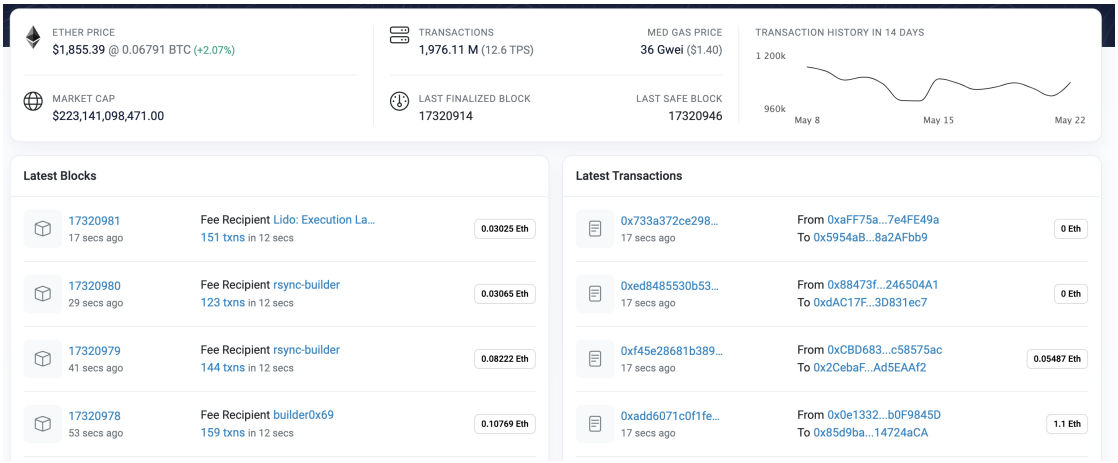
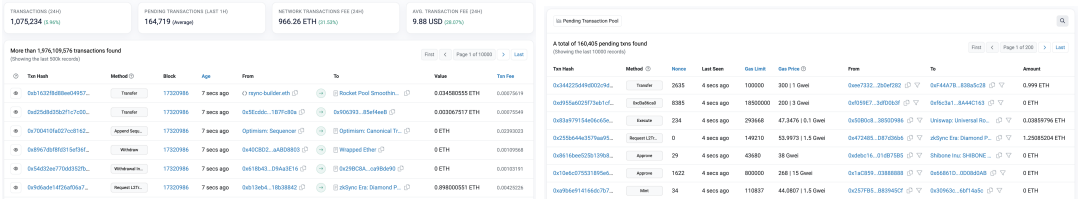


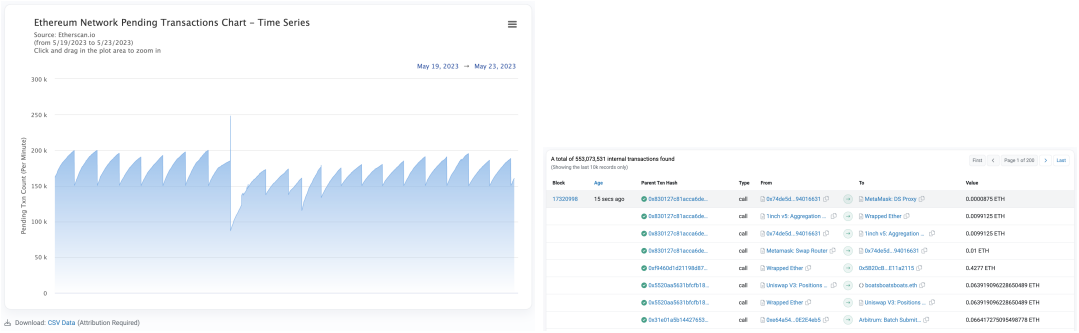
Figure 36: Etherscan home page, 23 May 2023

Detailed blockchain data



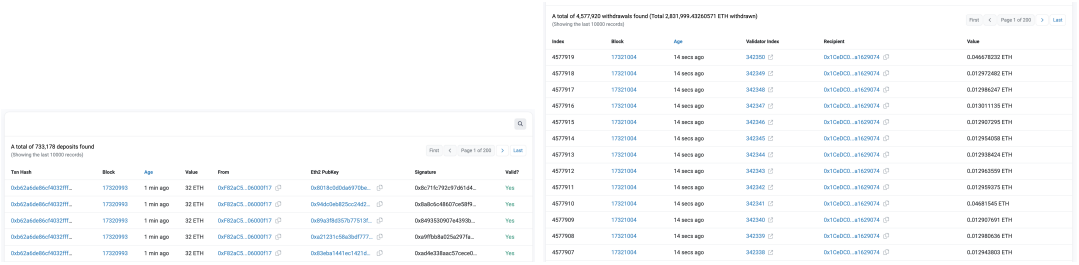
(a) (b)

Figure 37: Transactions (a) and pending transactions (b) from Etherscan (23 May 2023)



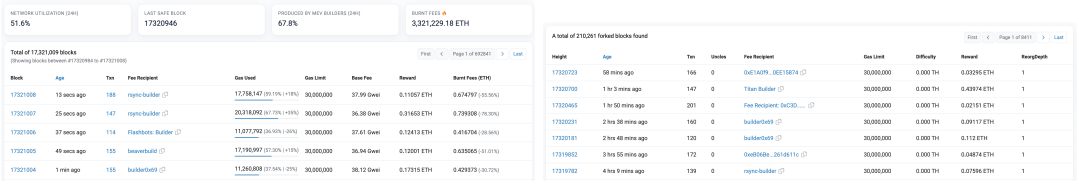
(a) (b)

Figure 38: Chart of pending transactions (a) and contract internal transactions (b) from Etherscan (23 May 2023)



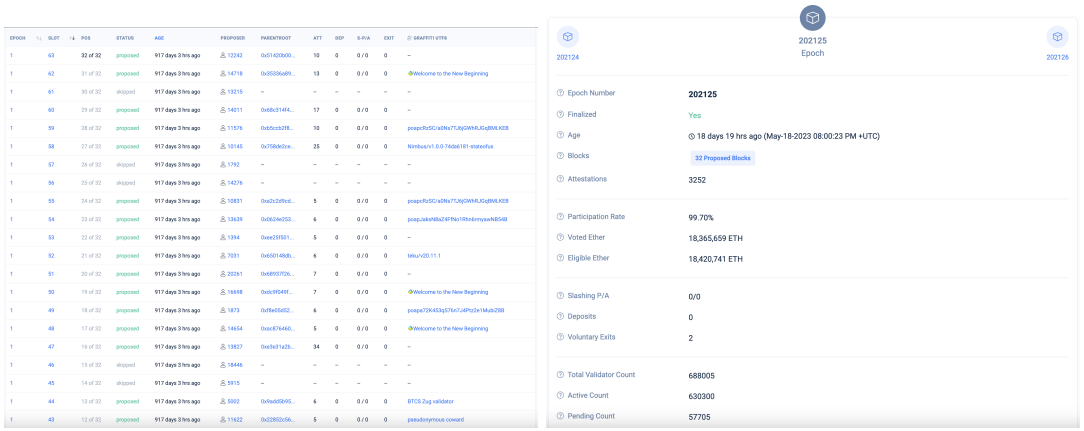
(a) (b)

Figure 39: Beacon chain deposits (a) and withdrawals (b) from Etherscan (23 May 2023)



(a) (b)

Figure 40: Details of beacon chain epochs (a) and forked blocks (b). Etherscan (23 May 2023)



(a) (b)

Figure 41: Details of beacon chain epochs (a) and detailed information for one epoch (b). Etherscan (7 June 2023)

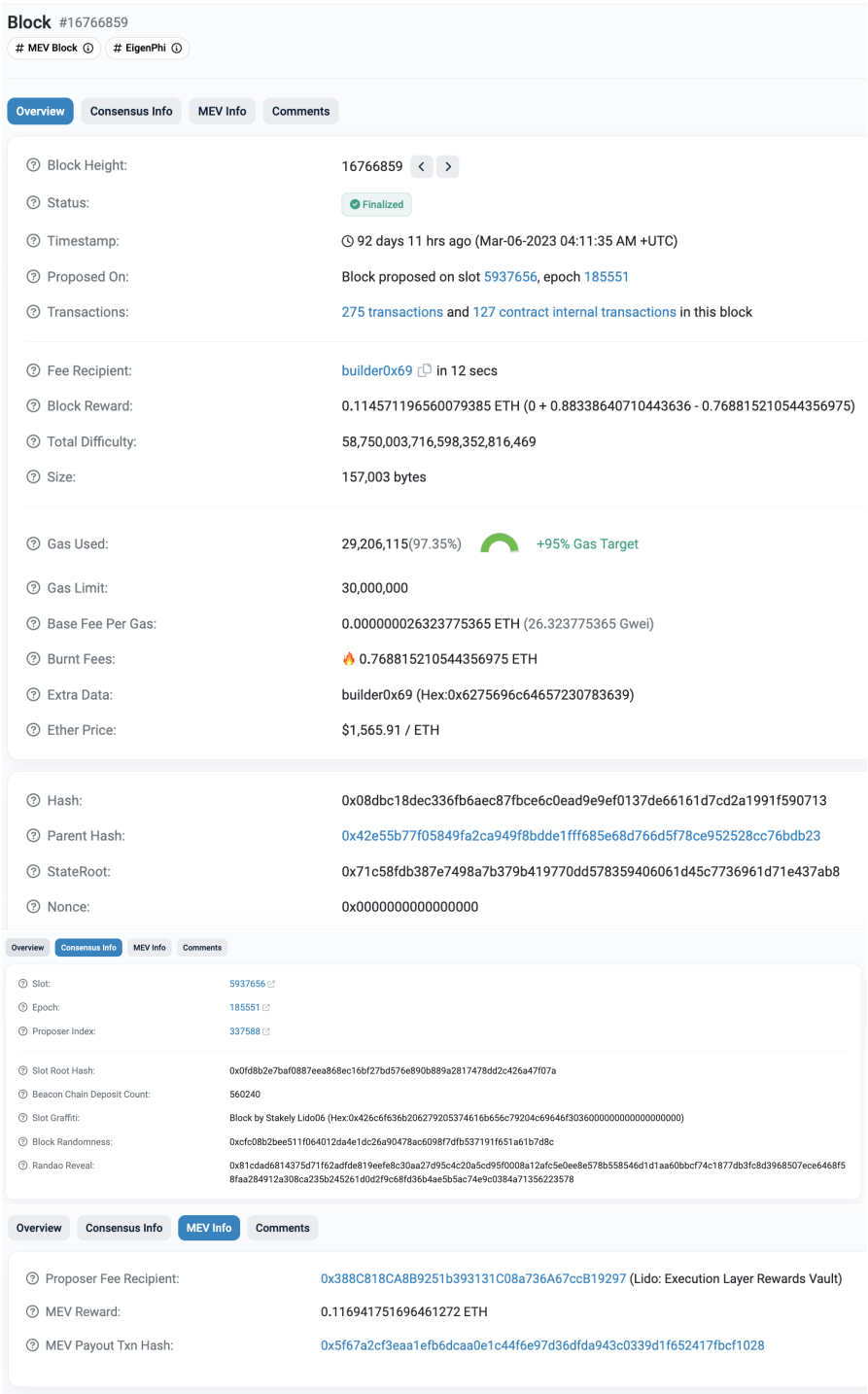
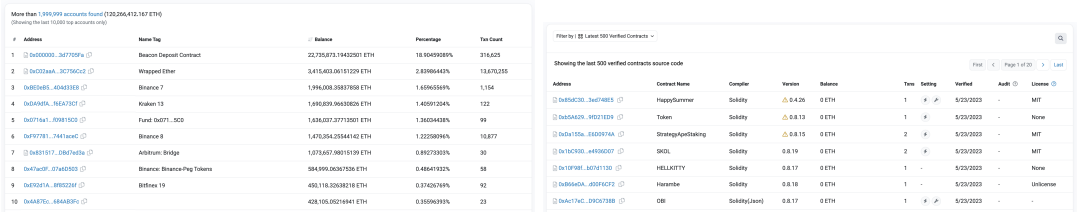
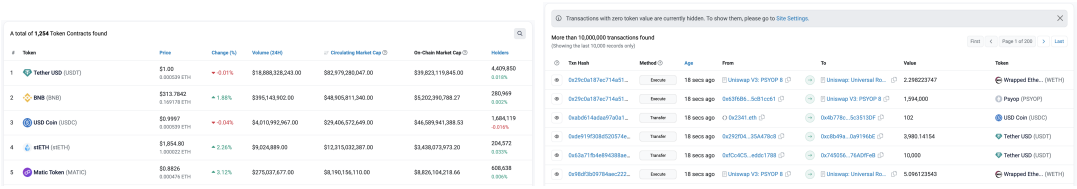


Figure 42: Detailed information of a block, e.g. block 16766859. Etherscan (7 June 2023)



(a) (b)

Figure 43: Top accounts by ETH balance (a) and verified contract source code (b). Etherscan (23 May 2023)



(a) (b)

Figure 44: Top ERC20 tokens (a) and ERC20 token transfers (b) from Etherscan (23 May 2023)

Charts and Statistics

Market data

Figure 45: Ether daily price (USD) from Etherscan, 23 May 2023

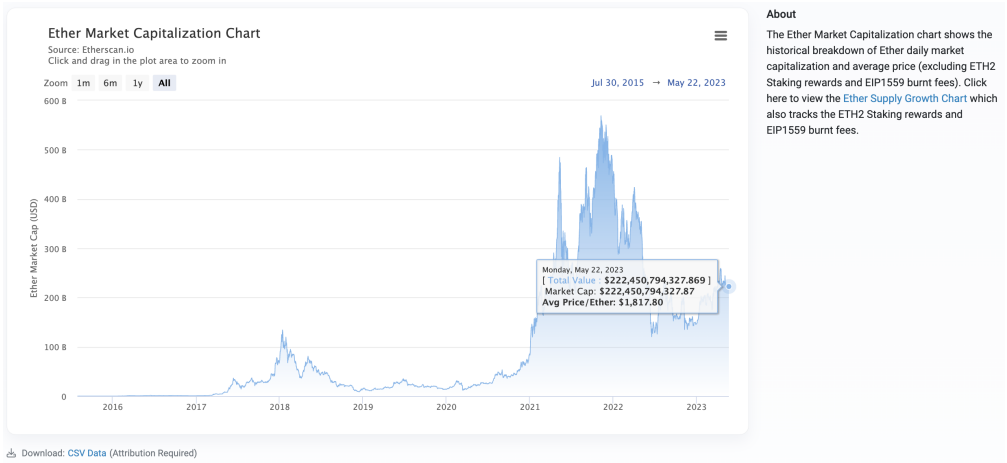


Figure 46: Ether market capitalisation from Etherscan - select time range or zoom in on selected part of graph, hover mouse for details (as shown), 23 May 2023

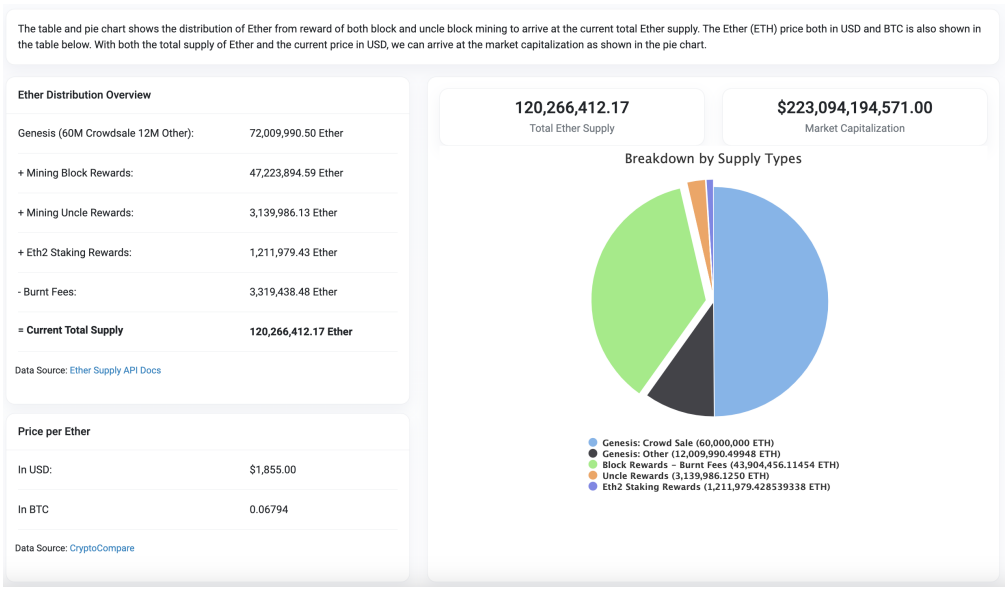


Figure 47: Ether total supply and market capitalisation from Etherscan, 23 May 2023

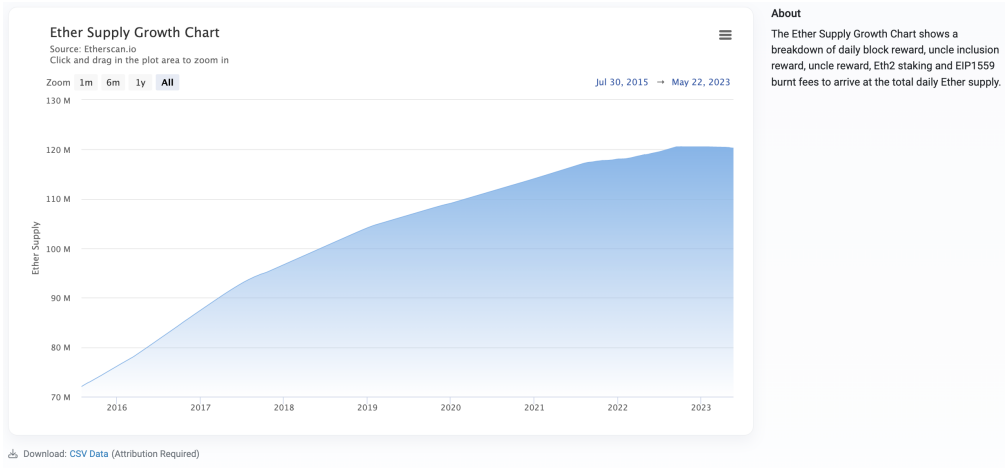


Figure 48: Ether supply growth chart from Etherscan - select time range or zoom in on selected part of graph, 23 May 2023

Blockchain data

Figure 49: Daily transactions. Etherscan, 20 June 2023

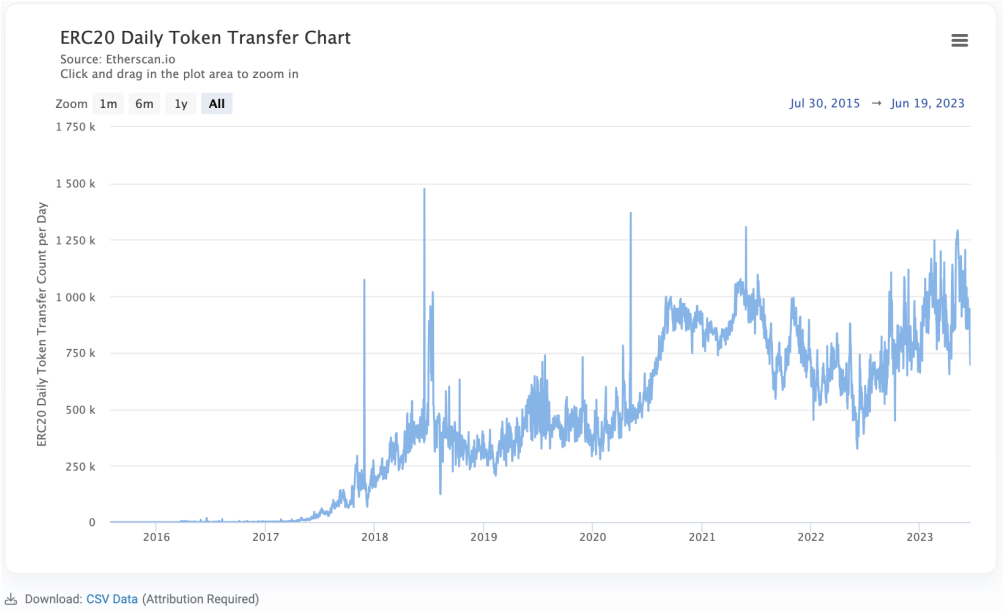


Figure 50: ERC20 Daily token transfers. Etherscan, 20 June 2023

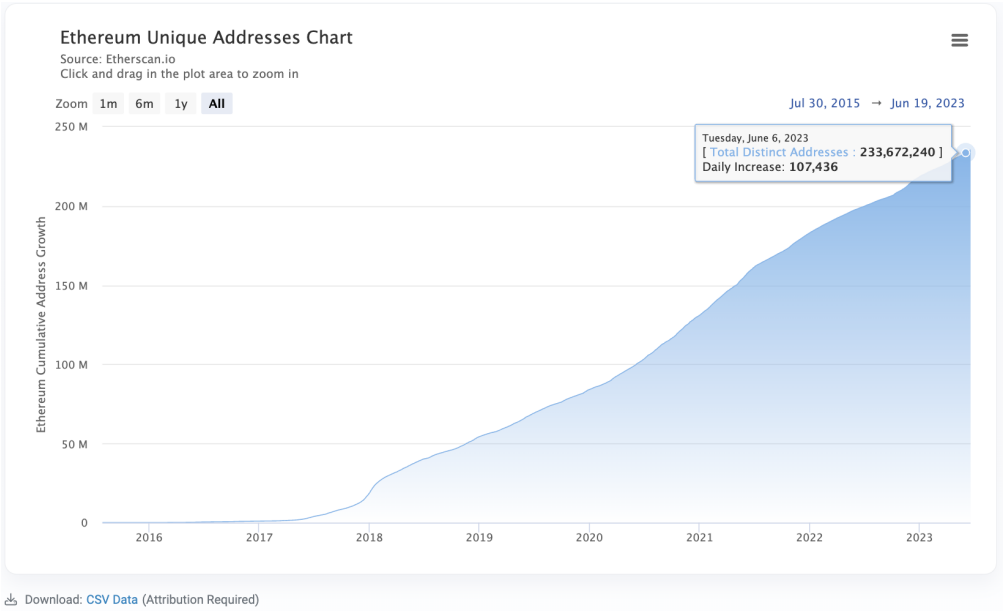


Figure 51: Chart of Ethereum unique addresses. Etherscan, 20 June 2023

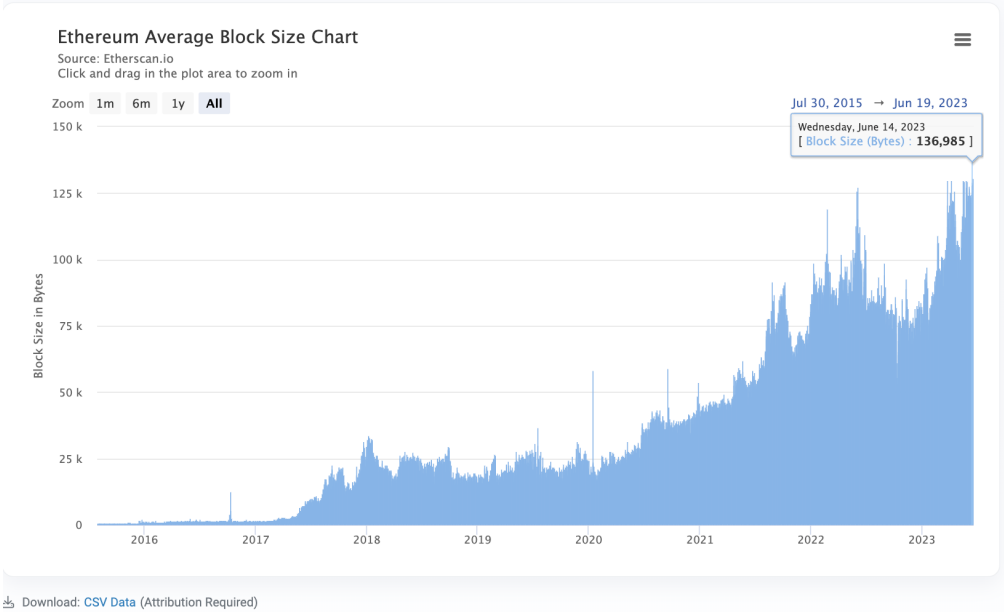


Figure 52: Ethereum average block size. Etherscan, 20 June 2023

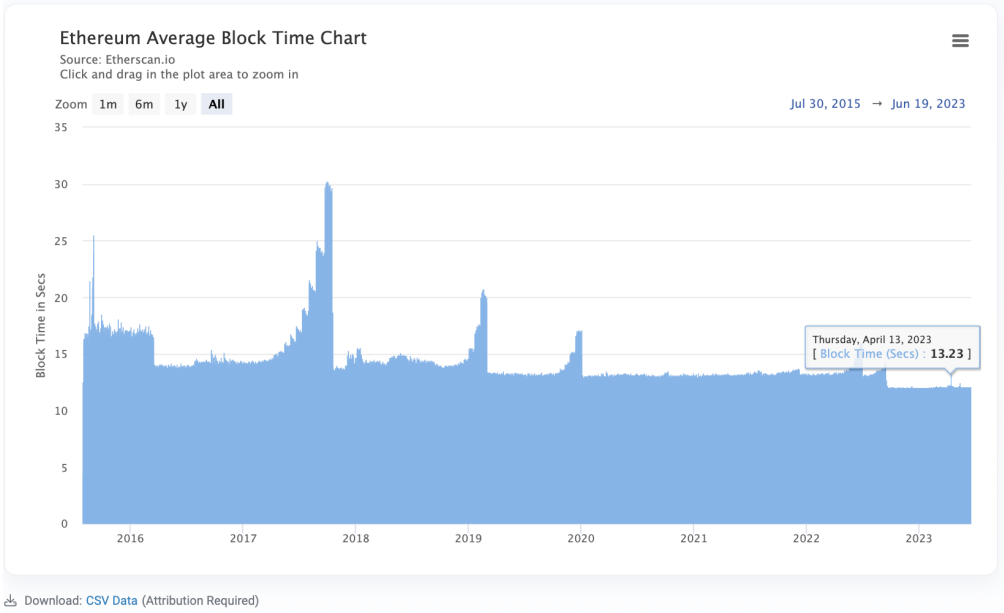


Figure 53: Ethereum average block time. Etherscan, 20 June 2023

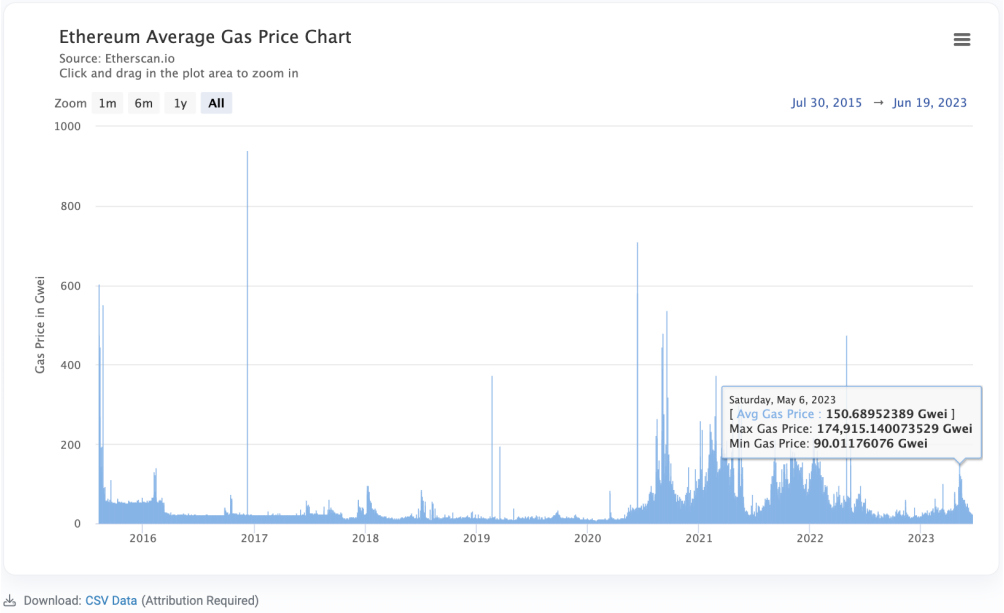


Figure 54: Ethereum average gas price. Etherscan, 20 June 2023

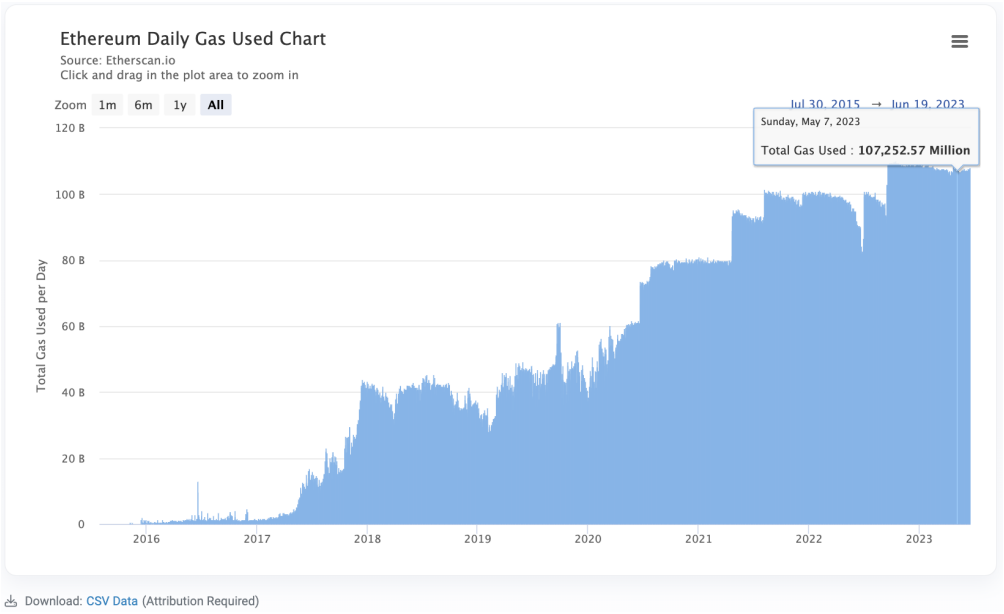


Figure 55: Ethereum average gas limit. Etherscan, 20 June 2023

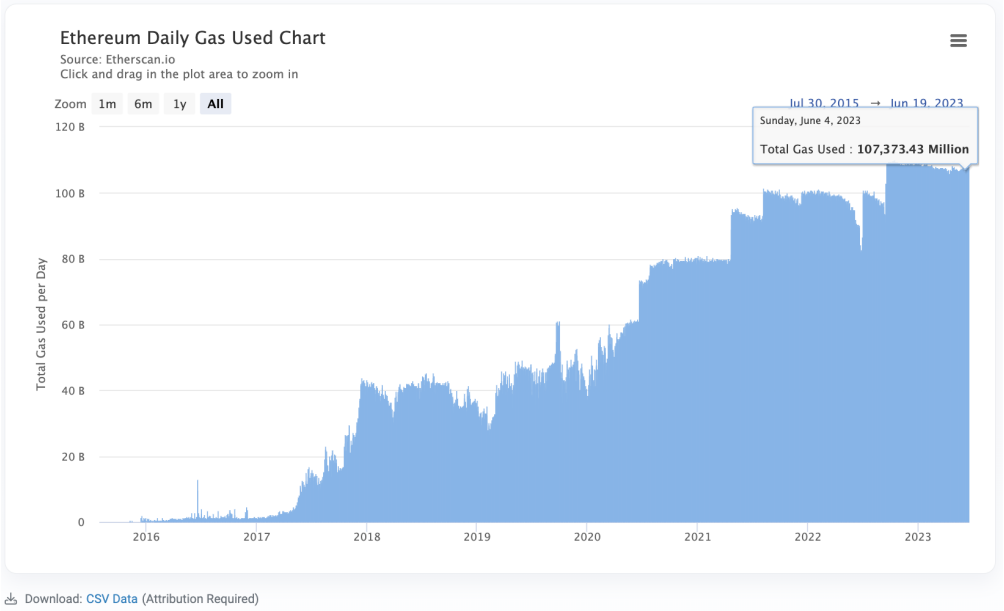


Figure 56: Ethereum daily gas used. Etherscan, 20 June 2023

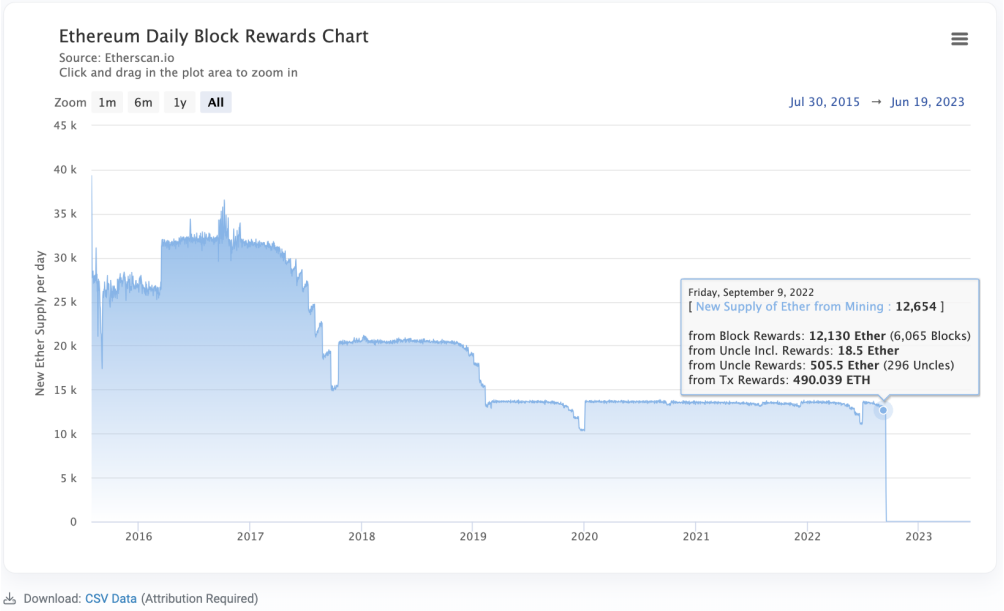


Figure 57: Ethereum block rewards. Etherscan, 20 June 2023

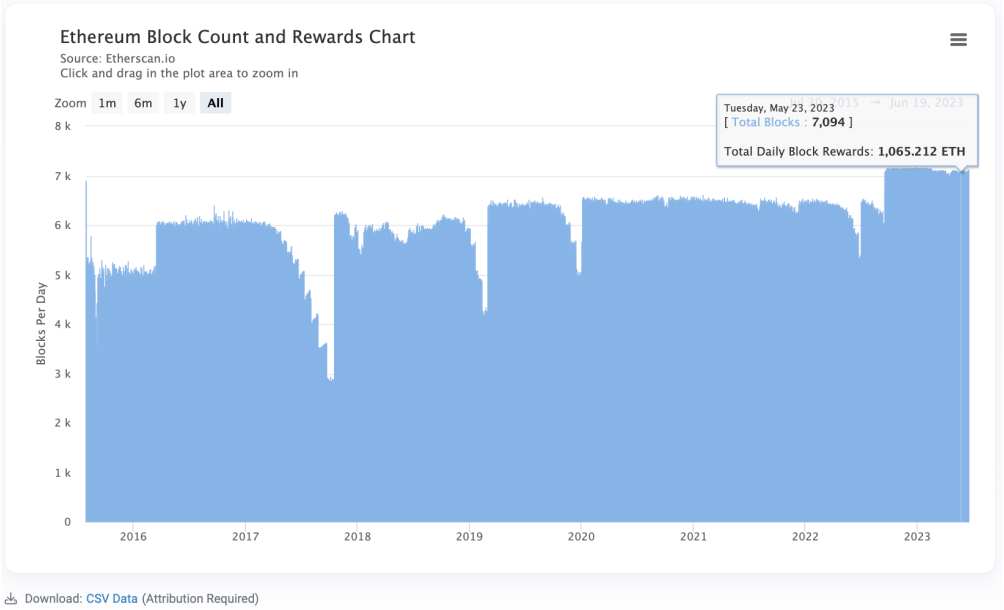


Figure 58: Ethereum block rewards. Etherscan, 20 June 2023

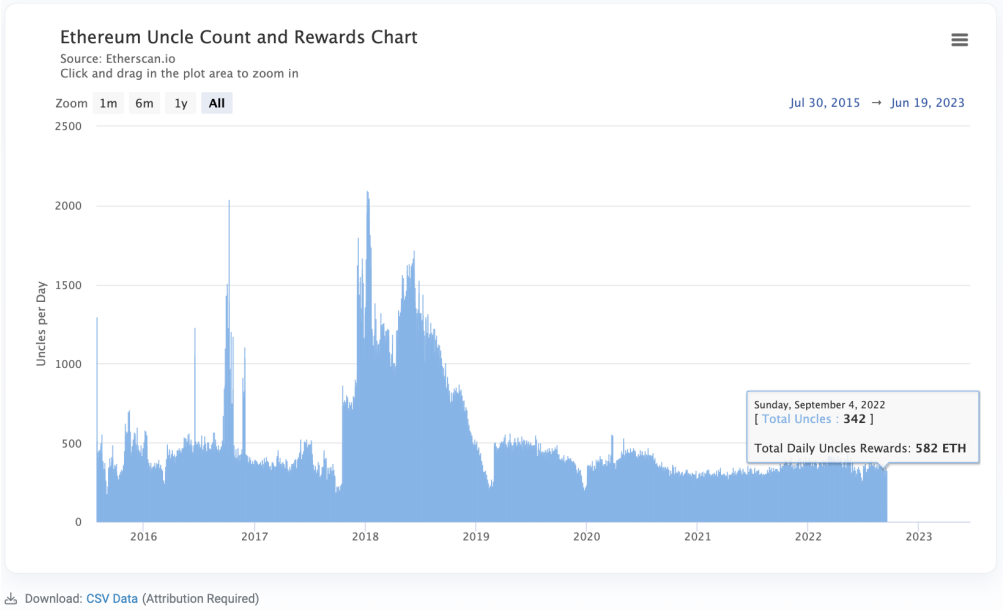


Figure 59: Ethereum uncle count and rewards. Etherscan, 20 June 2023

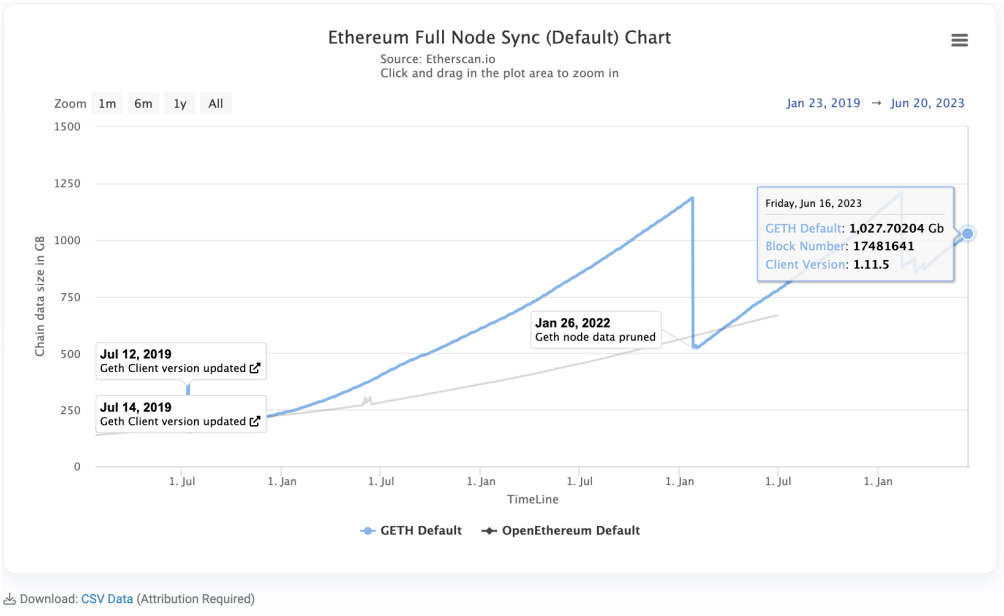


Figure 60: Ethereum full node sync (default). Etherscan, 20 June 2023

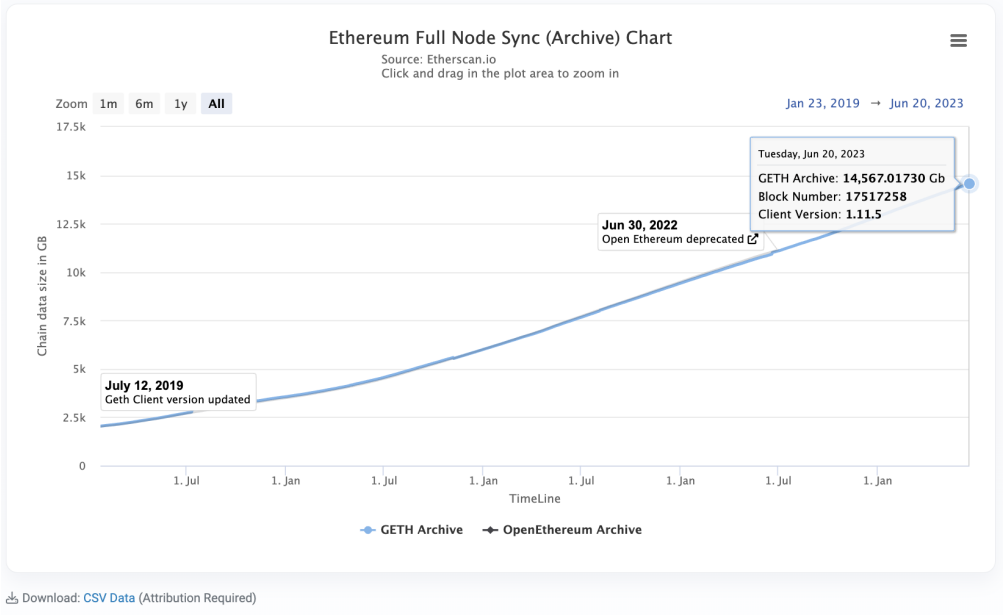


Figure 61: Ethereum full node sync (archive). Etherscan, 20 June 2023

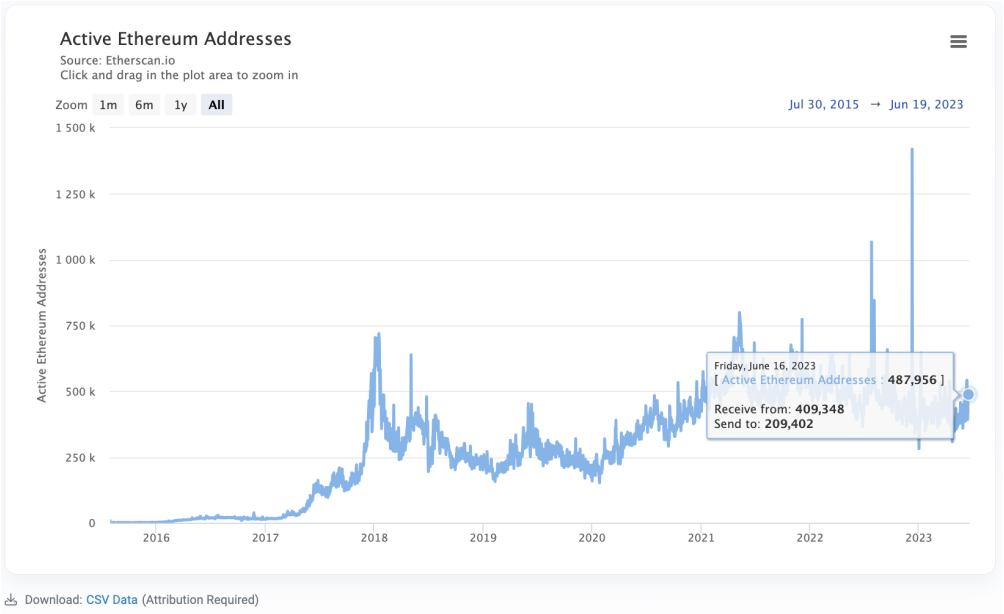


Figure 62: Daily active Ethereum addresses. Etherscan, 20 June 2023

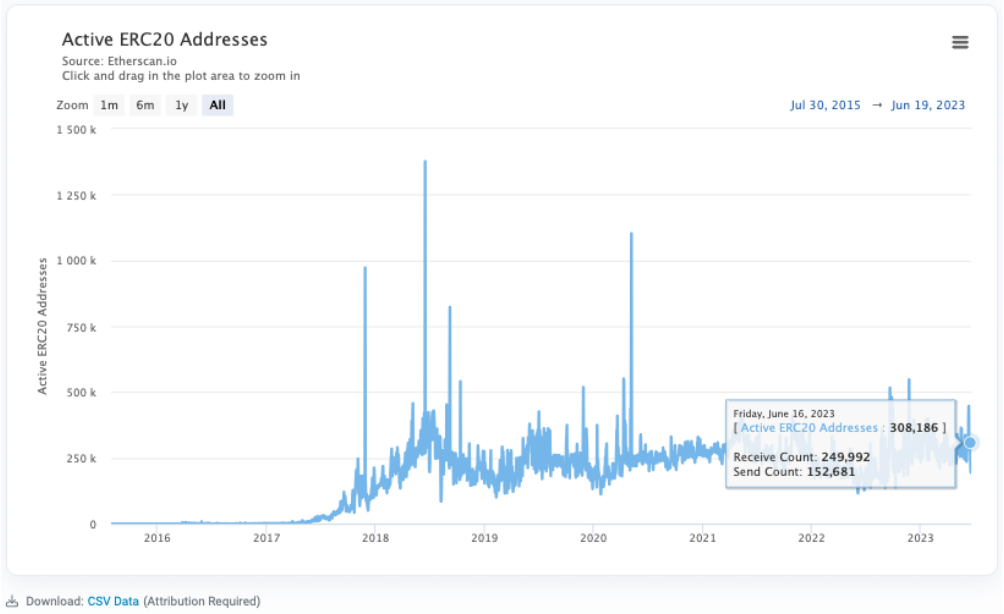


Figure 63: Daily active ERC20 addresses. Etherscan, 20 June 2023

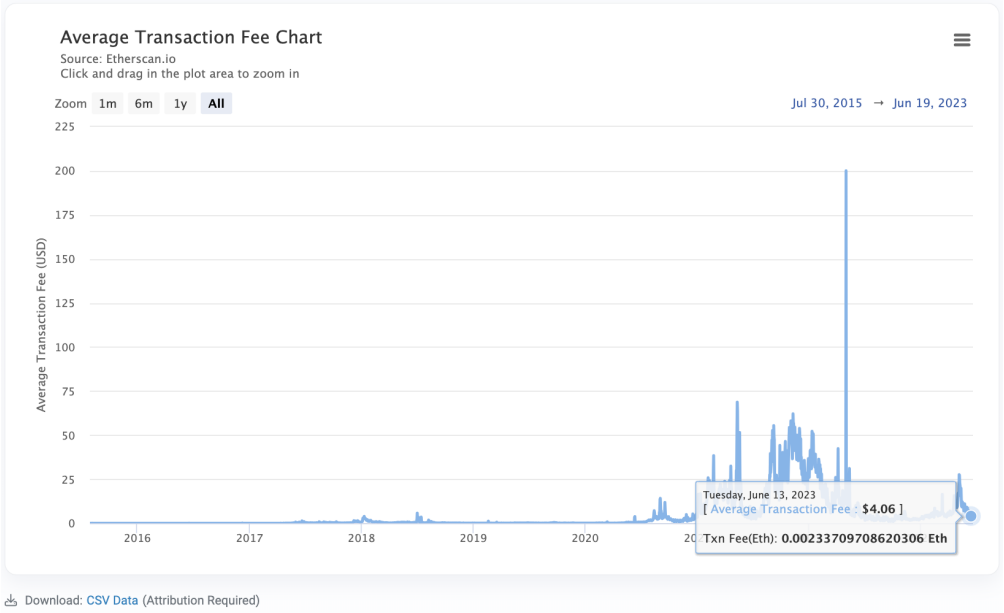


Figure 64: Average transaction fees. Etherscan, 20 June 2023

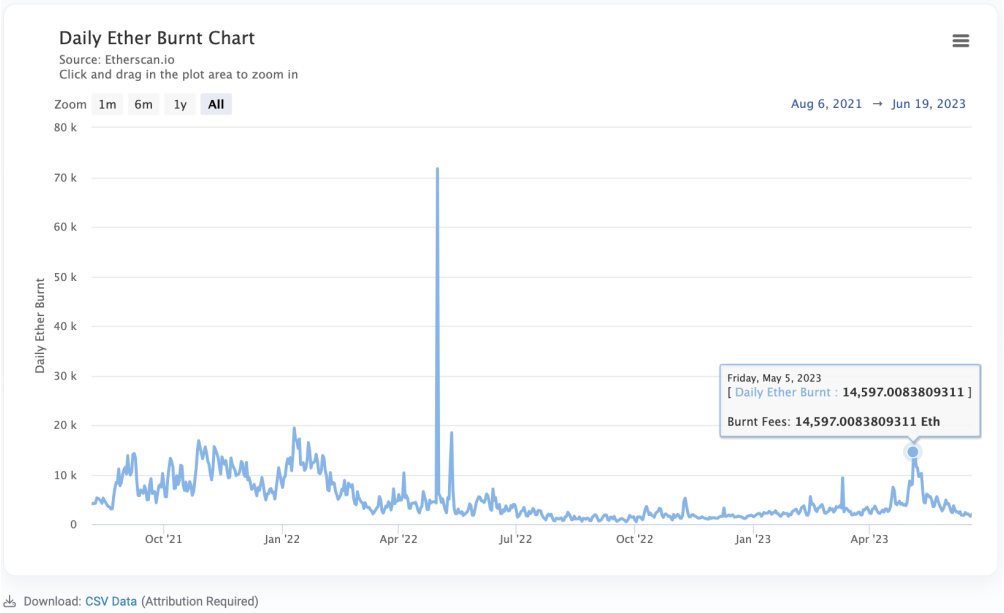


Figure 65: Daily ETH burnt. Etherscan, 20 June 2023

Dashboards

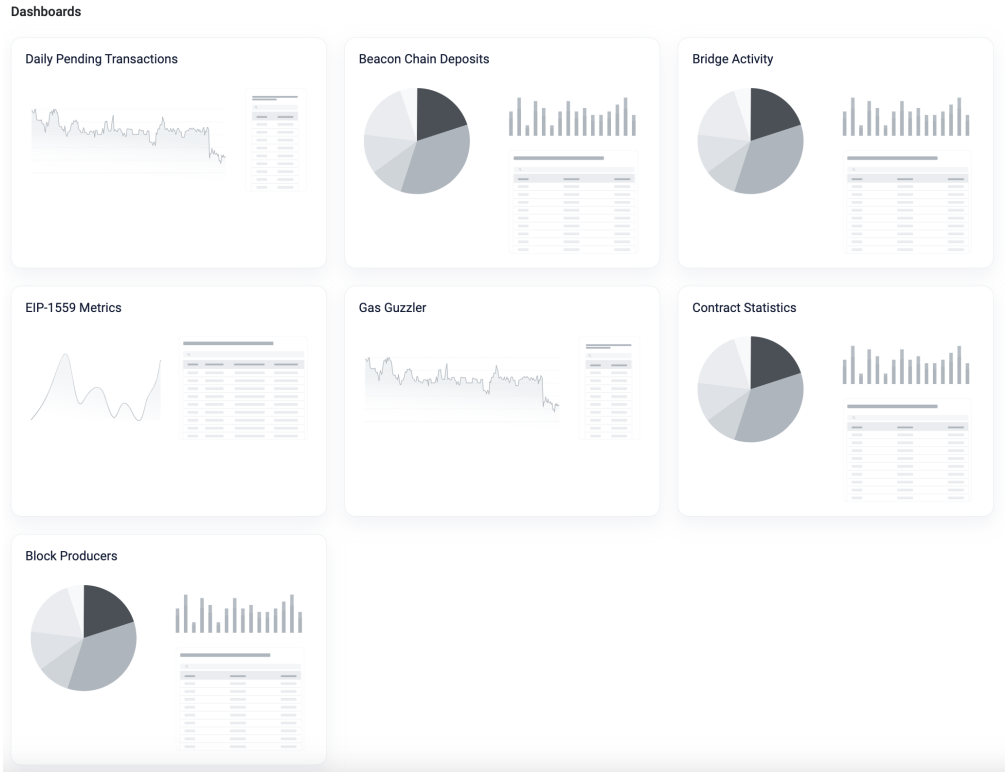


Figure 66: Screen shot of additional dashboards that are available to complement the visualisations already shown, 23 May 2023

Network data

Figure 67: Network hash rate, 20 June 2023

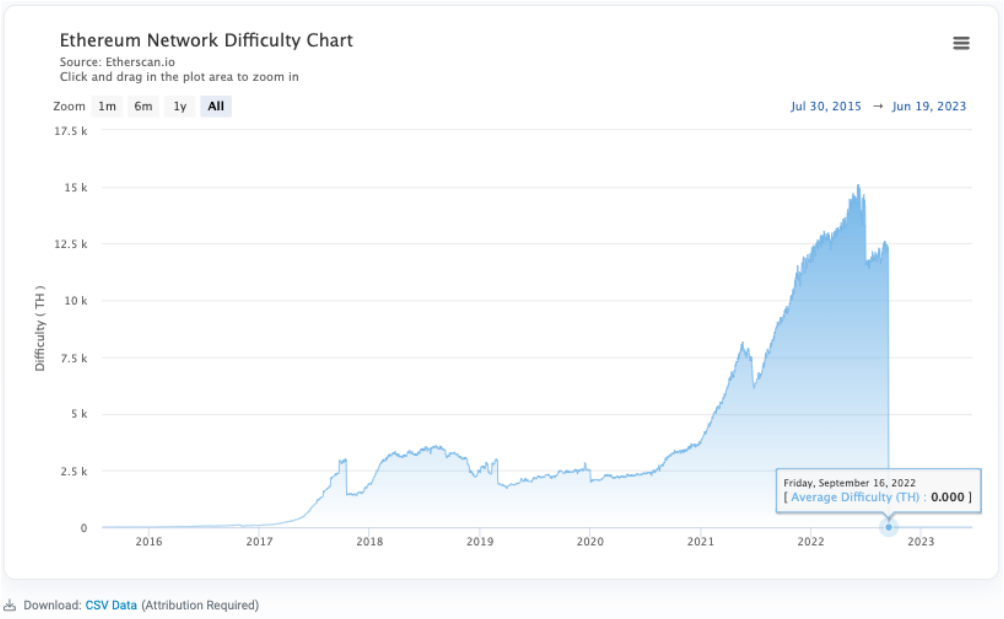


Figure 68: Network difficulty (pre-merge), 20 June 2023

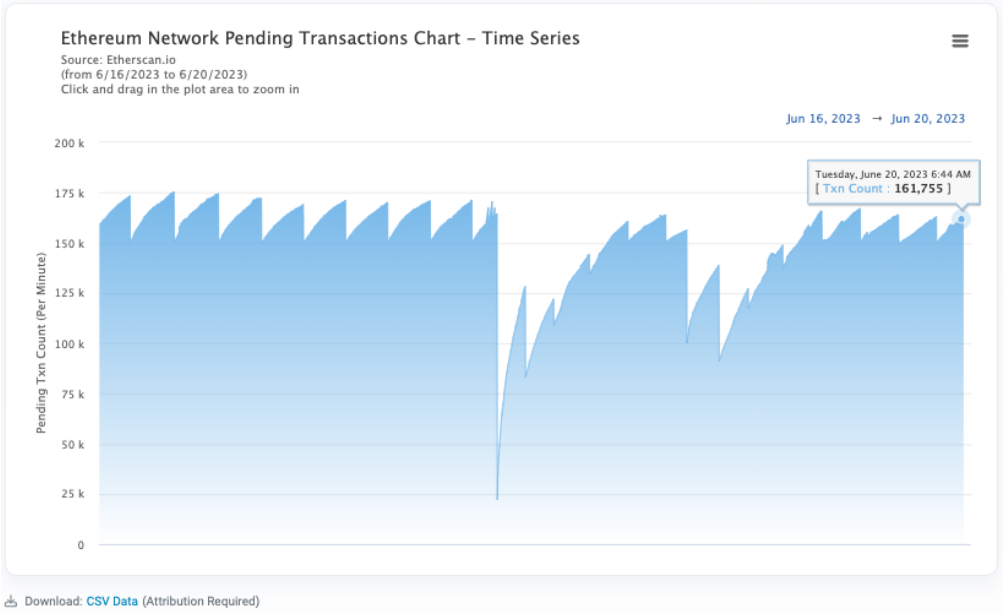


Figure 69: Network pending transactions, 20 June 2023

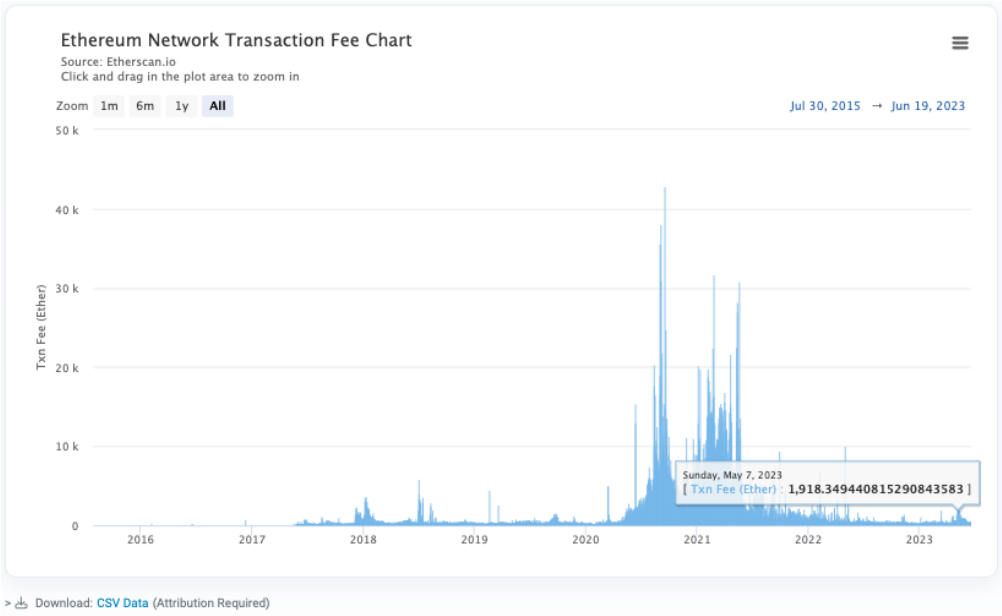


Figure 70: Network transaction fee, 20 June 2023

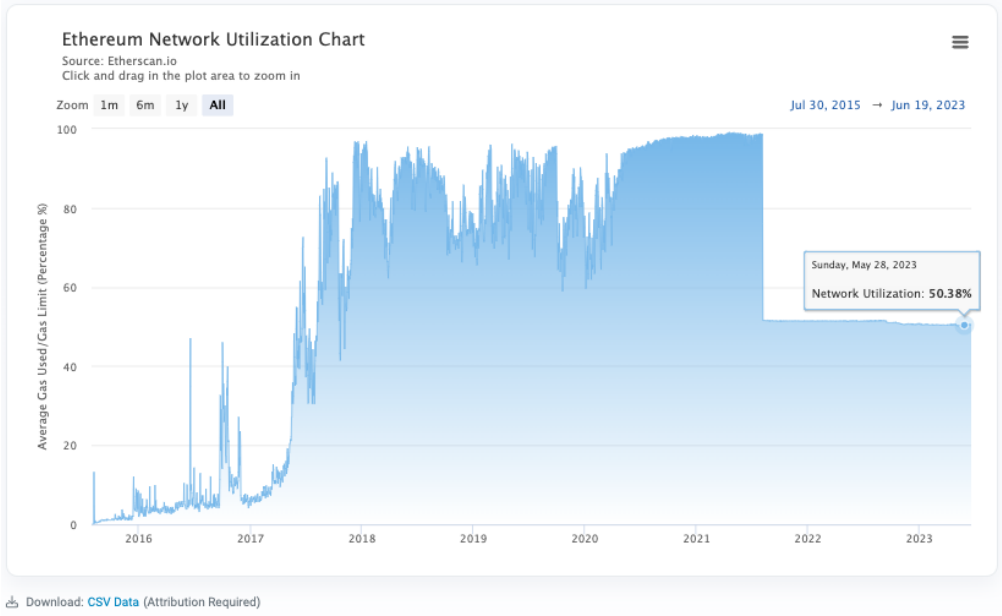


Figure 71: Network utilisation, 20 June 2023

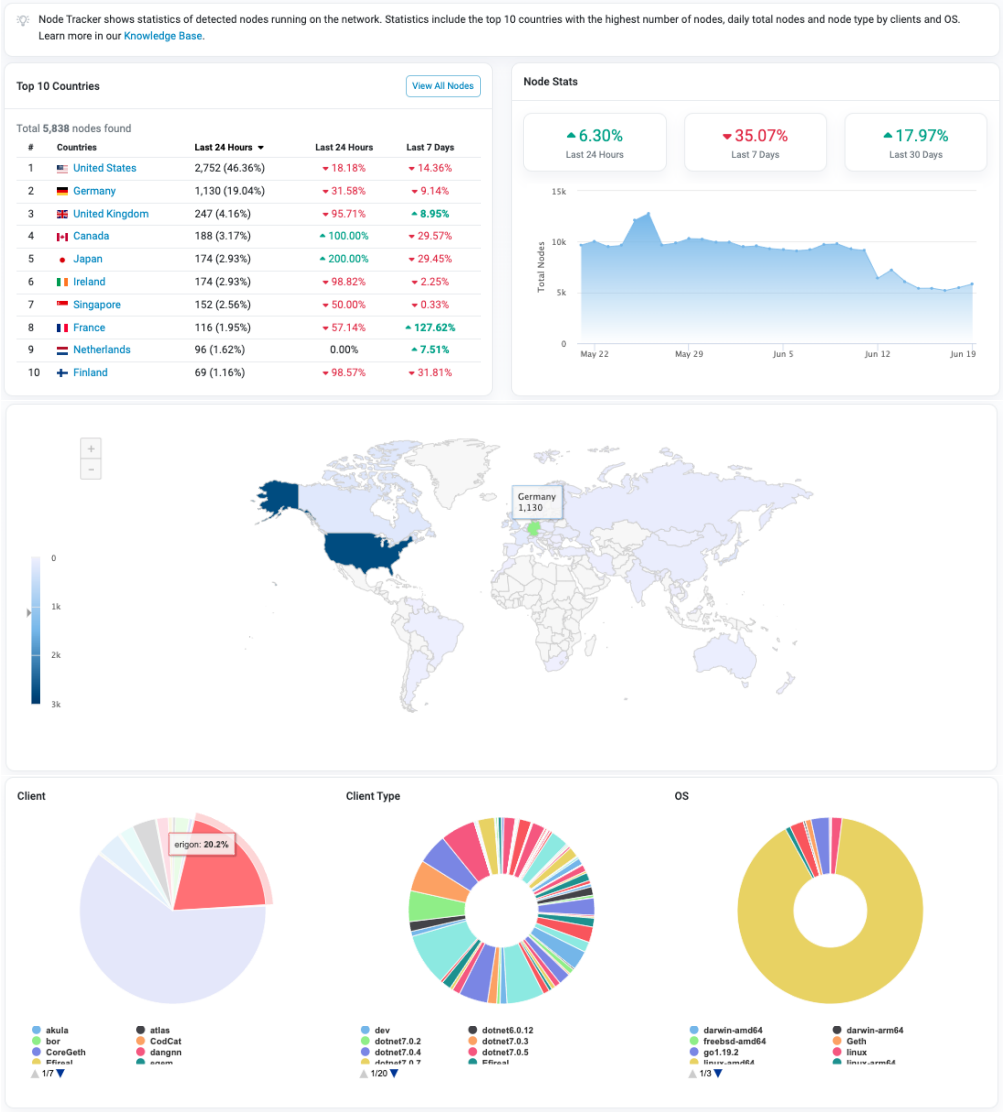


Figure 72: Node tracker, 20 June 2023

Contracts

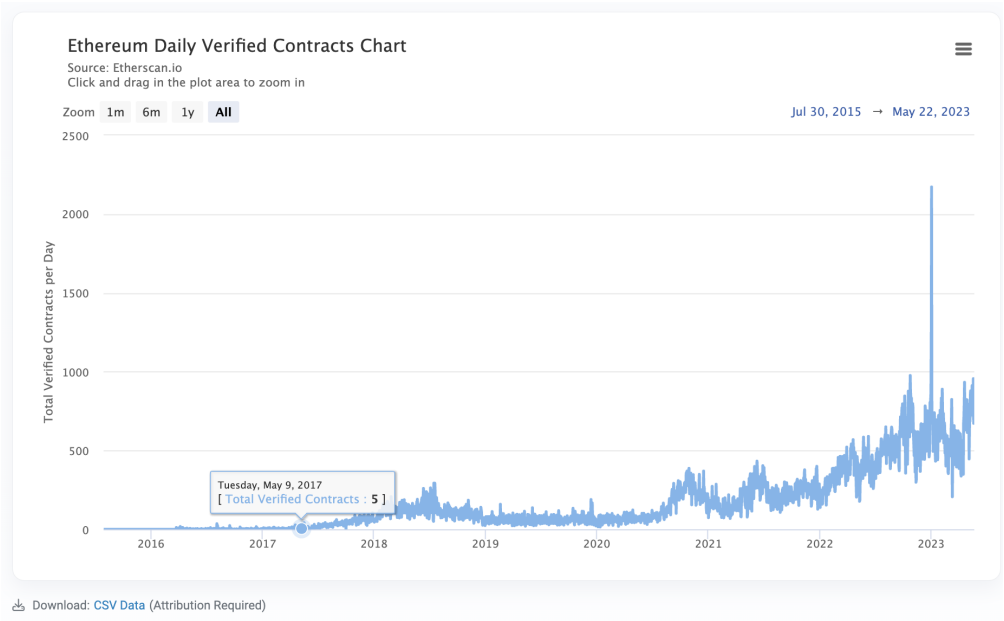


Figure 73: Daily verified contracts - select time range or zoom in on selected part of graph, 23 May 2023

Dune Analytics

Ethereum Staking

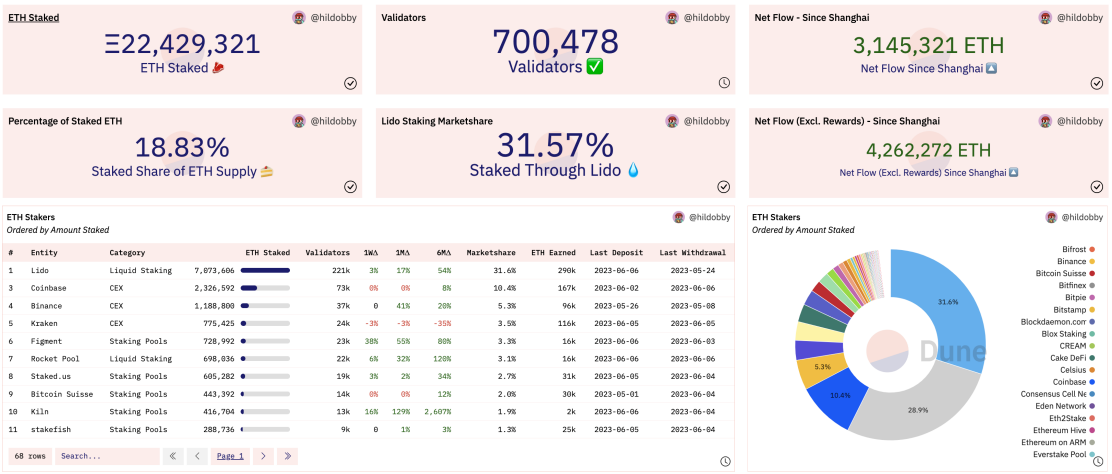


Figure 74: Dune Analytics Ethereum staking charts. @hildobby (7 June 2023)

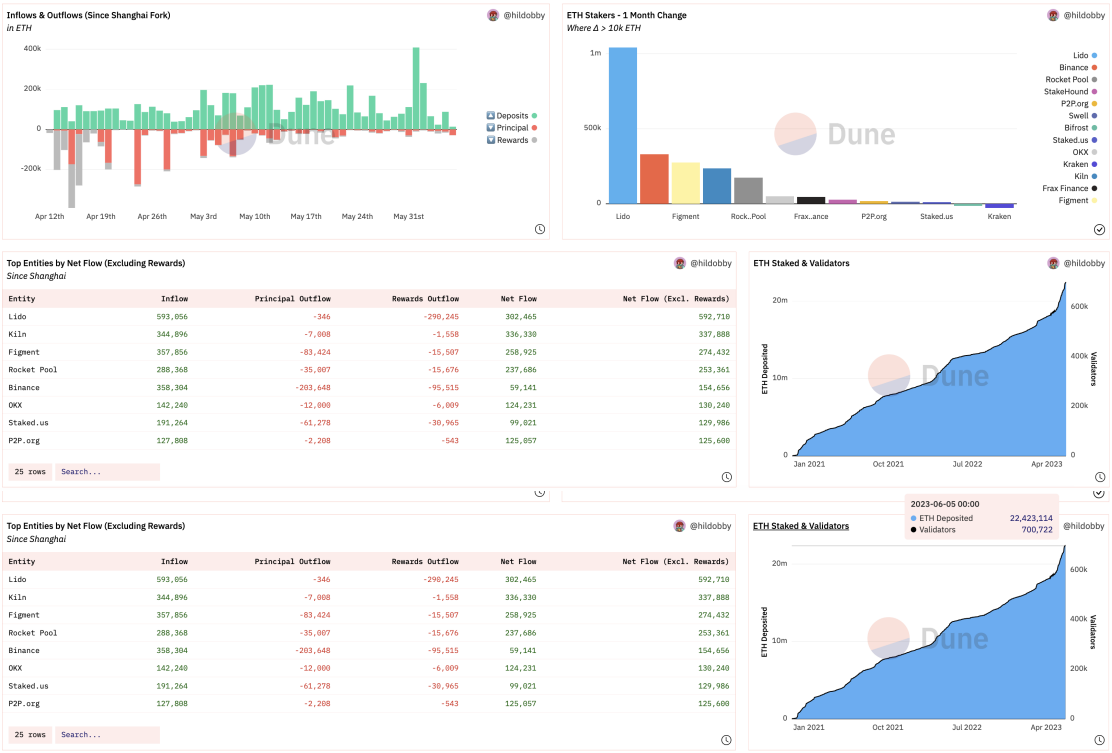


Figure 75: Dune Analytics ETH inflows and outflows, ETH staked and validators. @hildobby (7 June 2023)

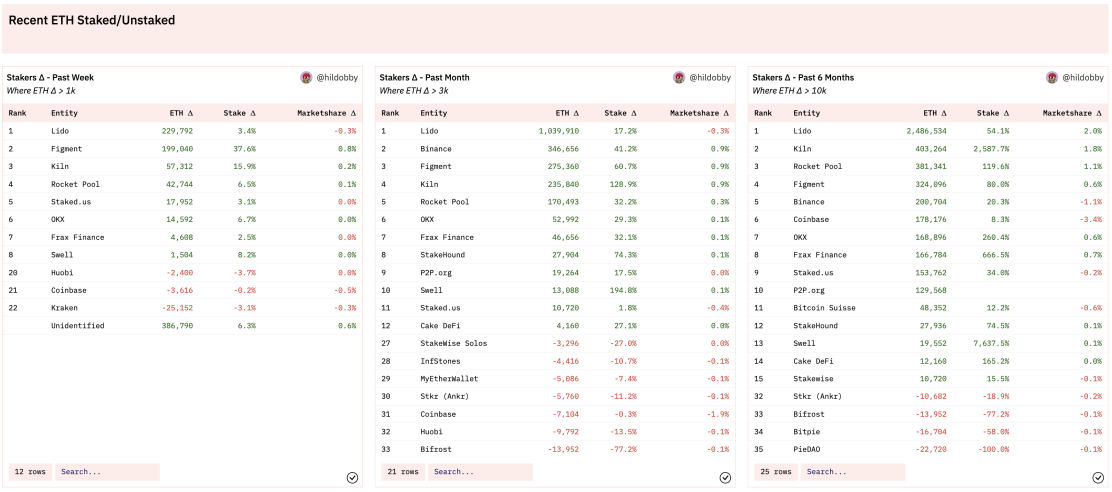


Figure 76: Dune Analytics Recent ETH staked. @hildobby (7 June 2023)

Figure 77: Dune Analytics ETH staked and withdrawn by entity. @hildobby (7 June 2023)

Figure 78: Dune Analytics ETH staked by entity and category. @hildobby (7 June 2023)

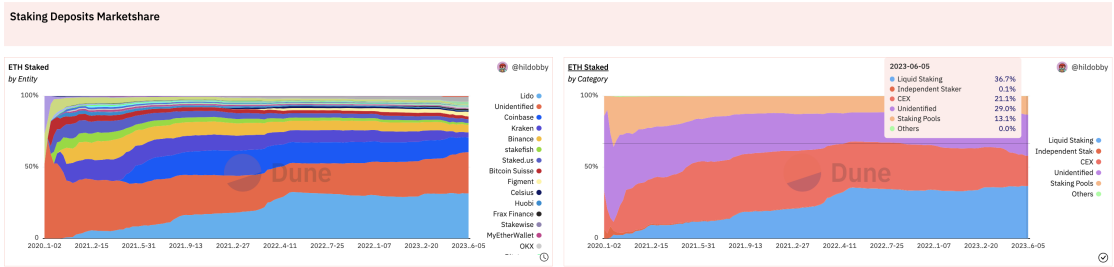


Figure 79: Dune Analytics Staking deposit market share. @hildobby (7 June 2023)

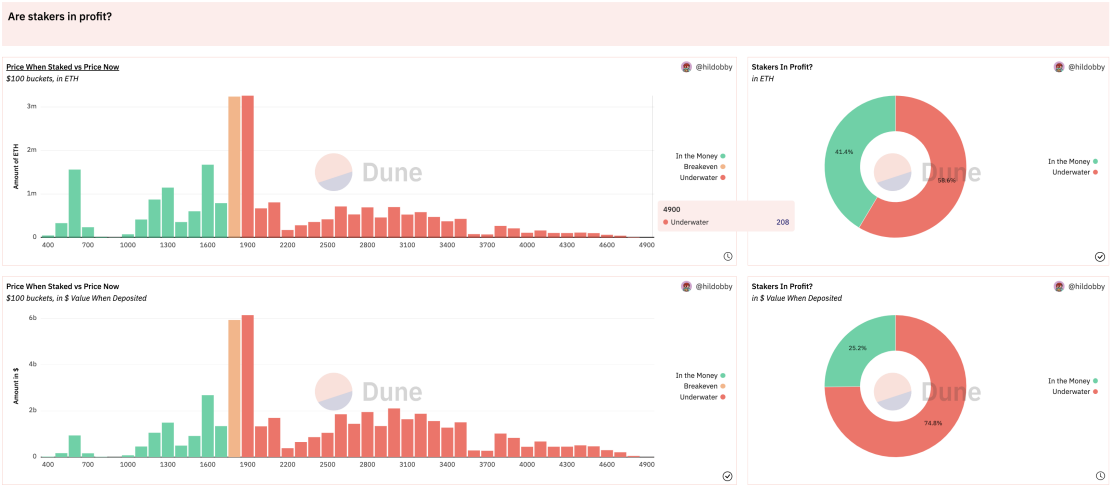


Figure 80: Dune Analytics Staker profit. @hildobby (7 June 2023)

LIDO

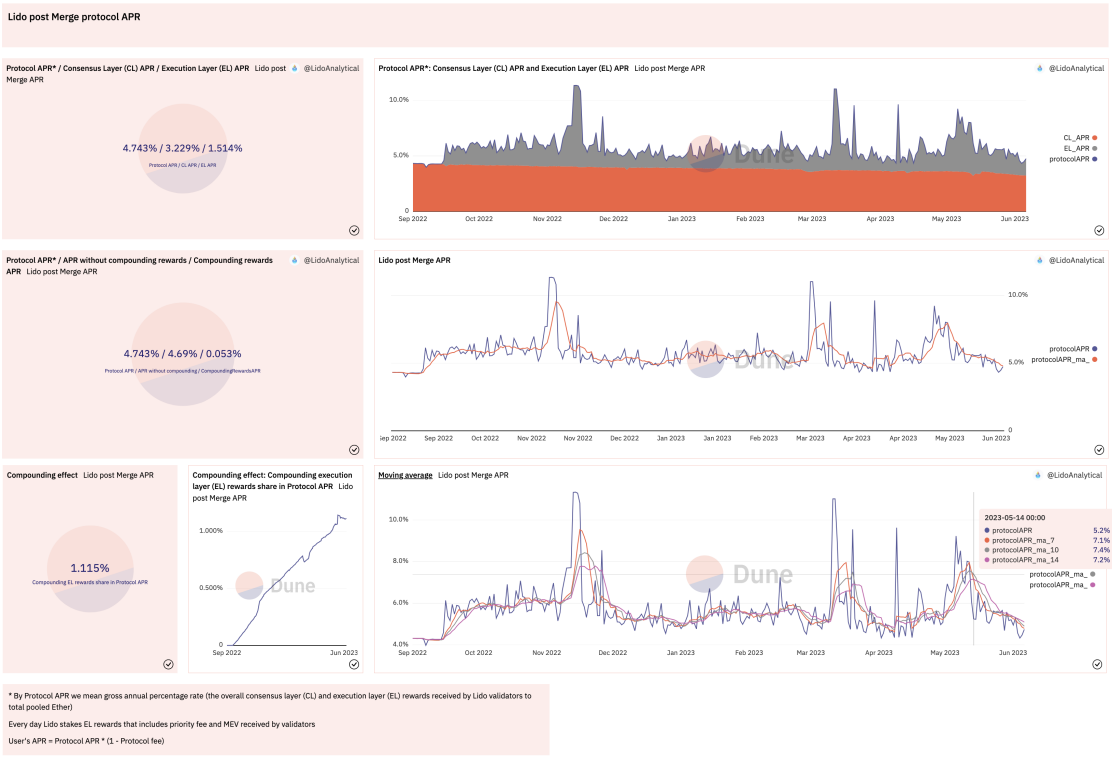


Figure 81: Dune Analytics Lido post Merge protocol APR dashboard by @LidoAnalytical (7 June 2023)

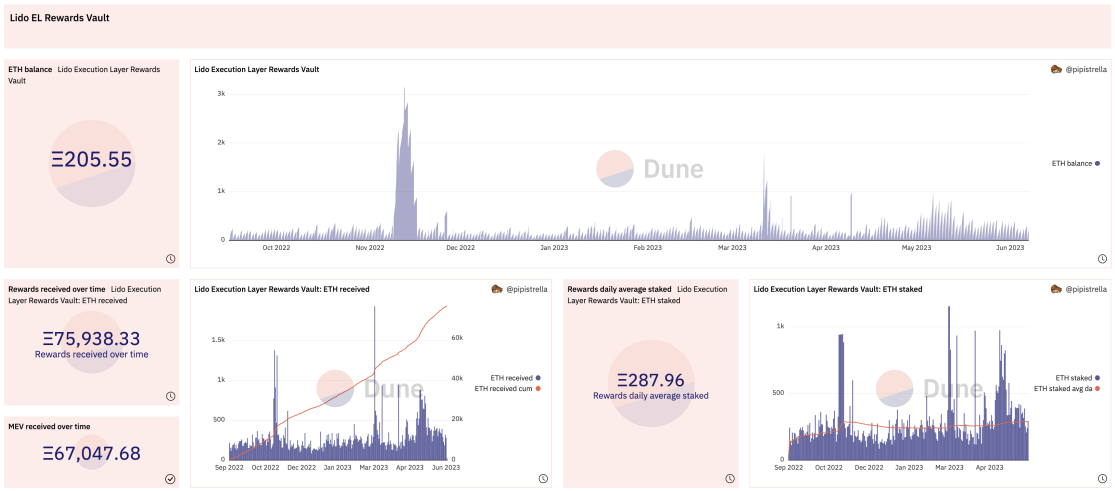


Figure 82: Dune Analytics Lido Execution Layer rewards by @LidoAnalytical (7 June 2023)

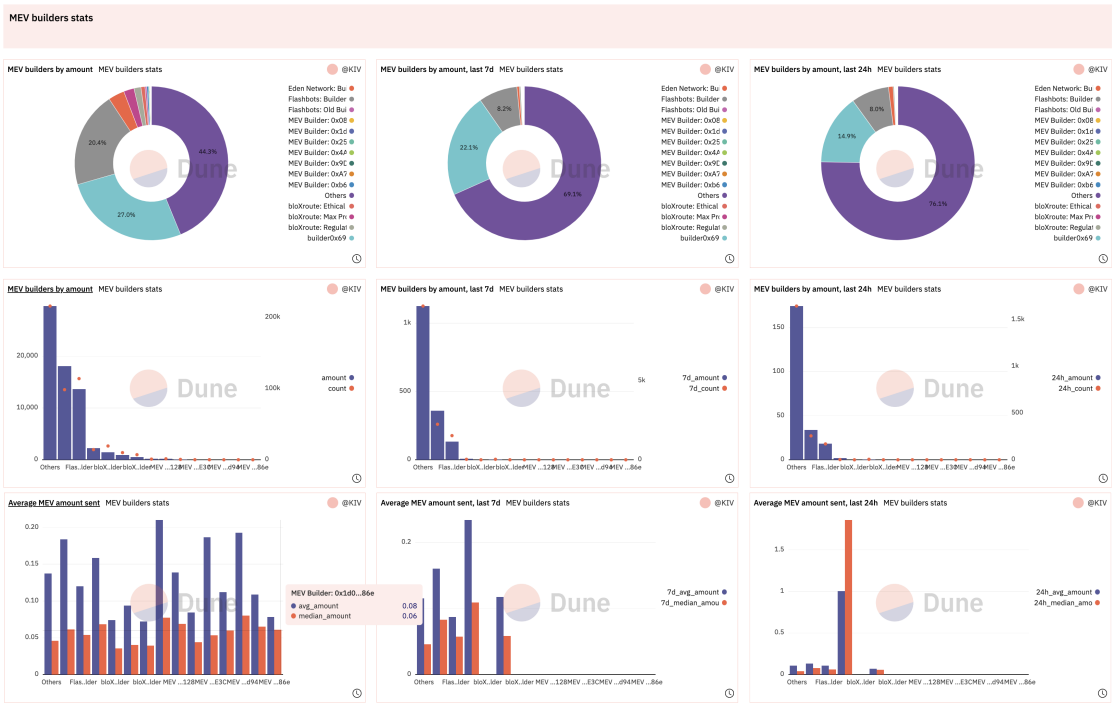


Figure 83: Dune Analytics Lido MEV builders statistics by @LidoAnalytical (7 June 2023)

Rocket Pool

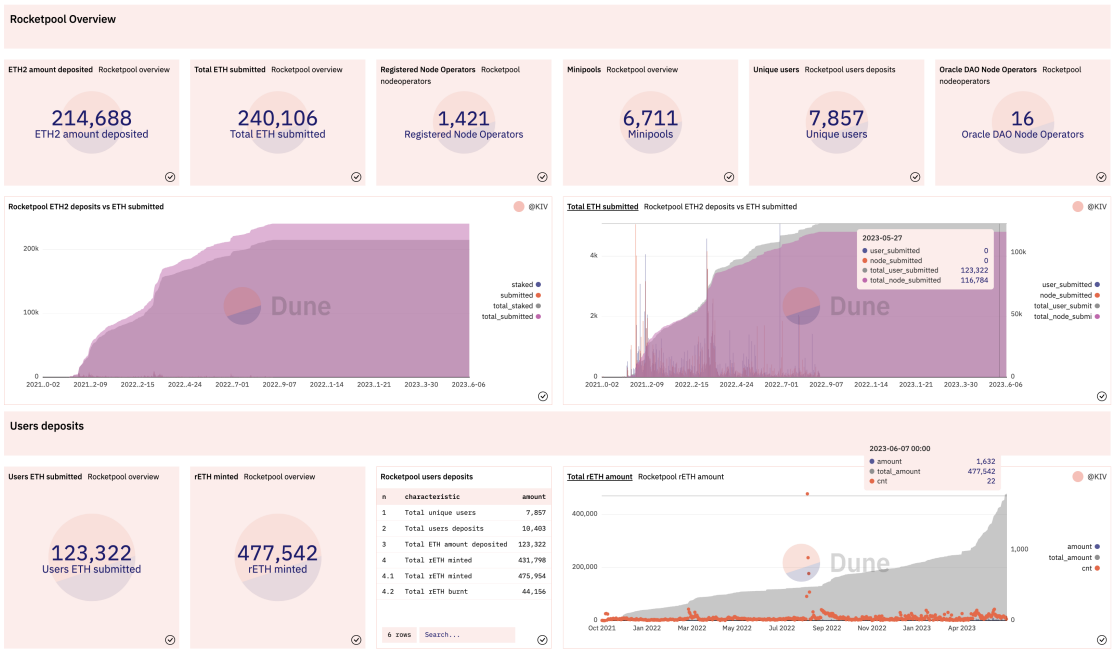


Figure 84: Dune Analytics Rocket Pool overview by @KIV (7 June 2023)

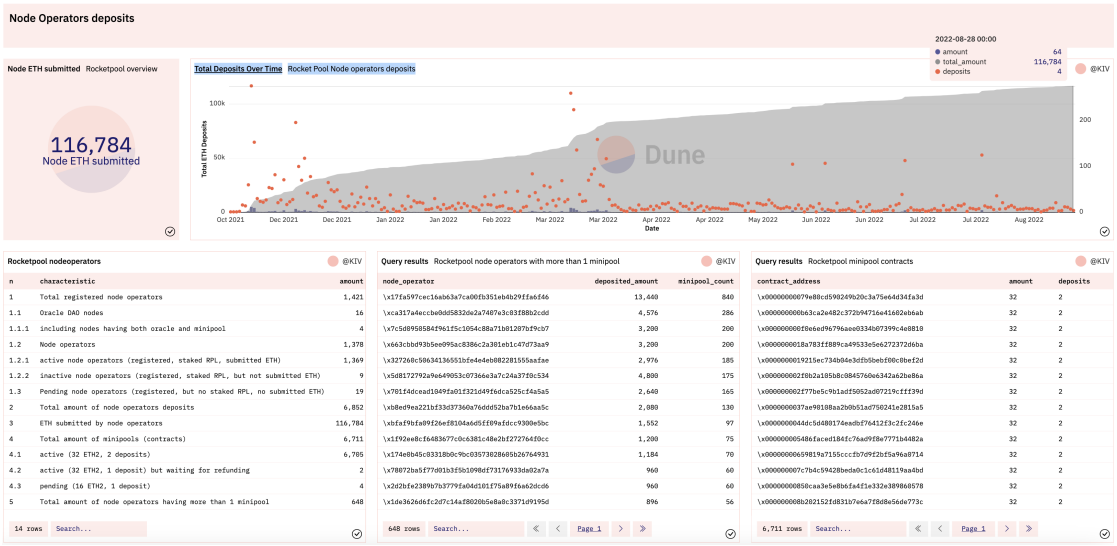


Figure 85: Dune Analytics Rocket Pool node operator deposits by @KIV (7 June 2023)

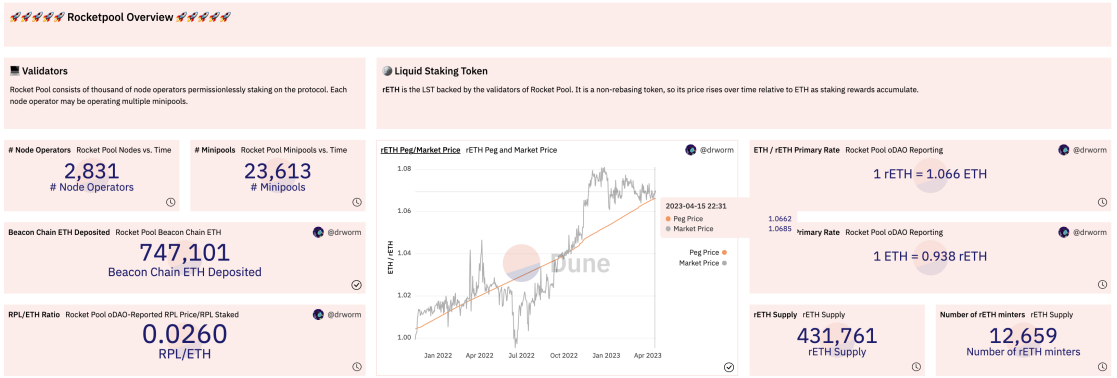


Figure 86: Dune Analytics Rocket Pool overview by @drworm (7 June 2023)

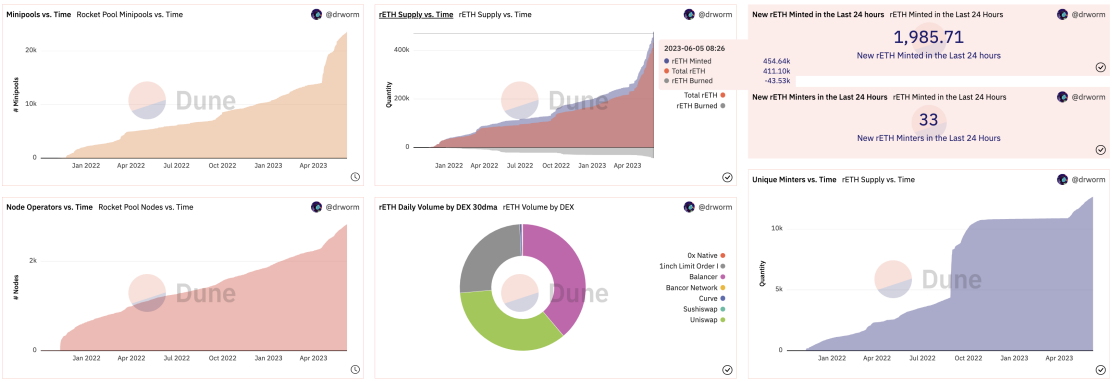


Figure 87: Dune Analytics Rocket Pool various statistics by @drworm (7 June 2023)

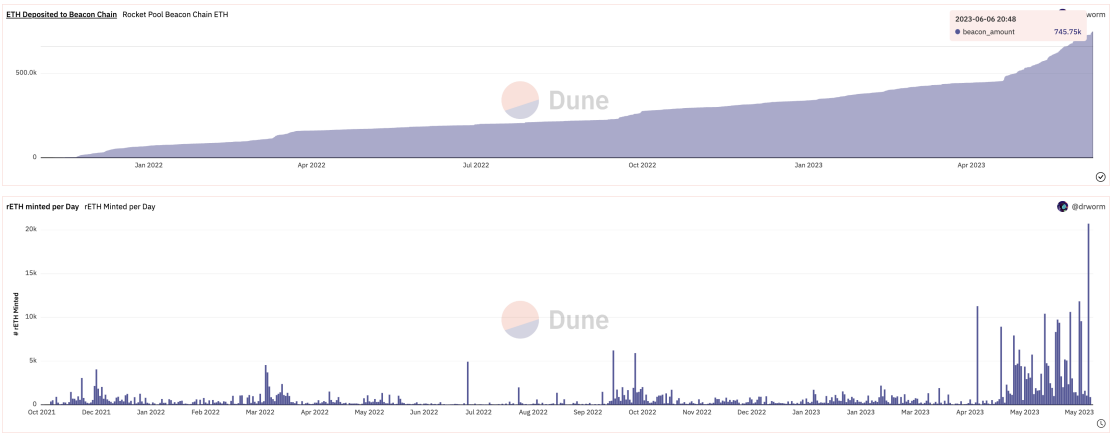


Figure 88: Dune Analytics Rocket Pool ETH deposited & rETH minted by @drworm (7 June 2023)

Figure 89: Dune Analytics Rocket Pool liquid staking derivatives peg price performance by @worm (7 June 2023)

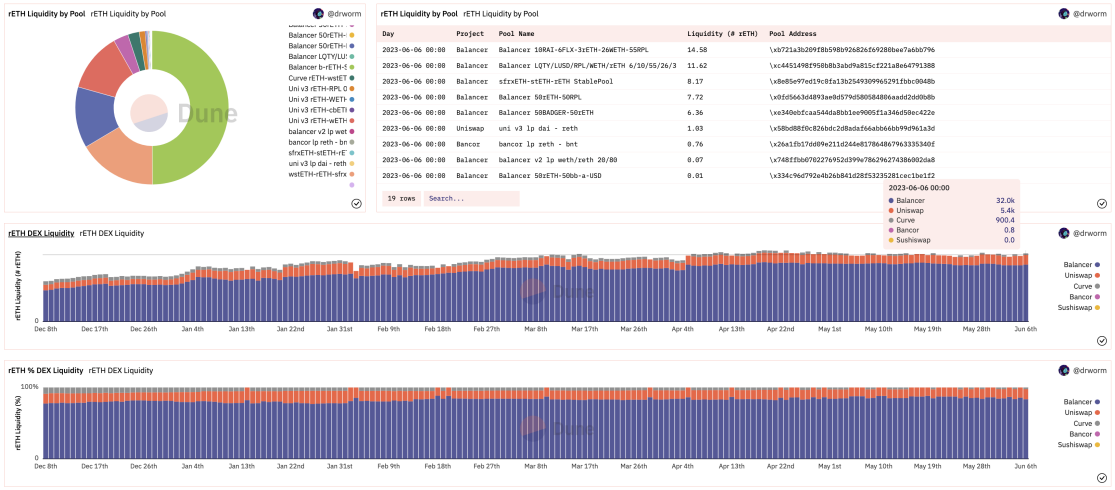


Figure 90: Dune Analytics Rocket Pool rETH liquidity by @drworm (7 June 2023)

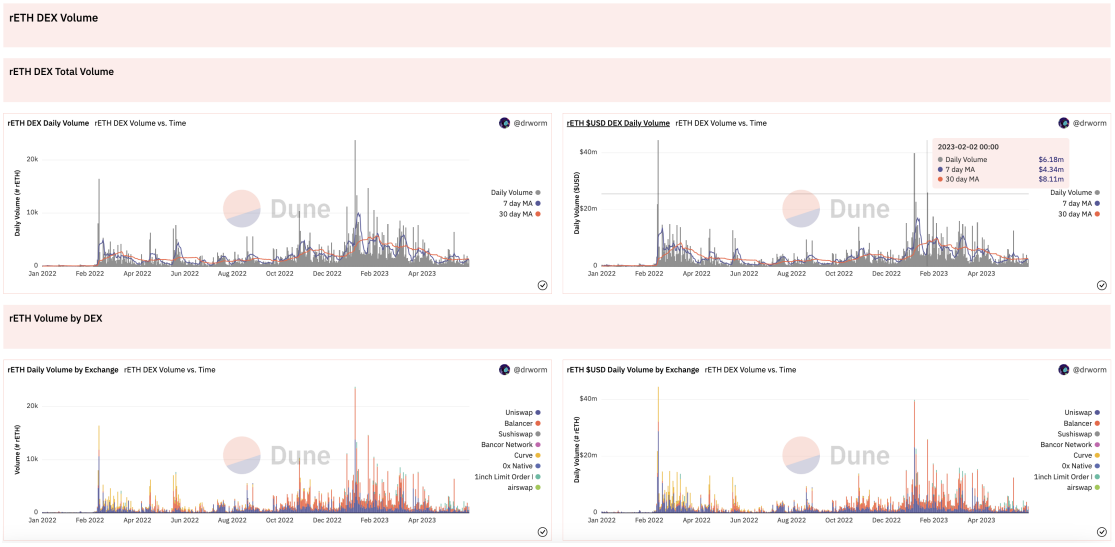


Figure 91: Dune Analytics Rocket Pool rETH DEX statistics by @drworm (7 June 2023)

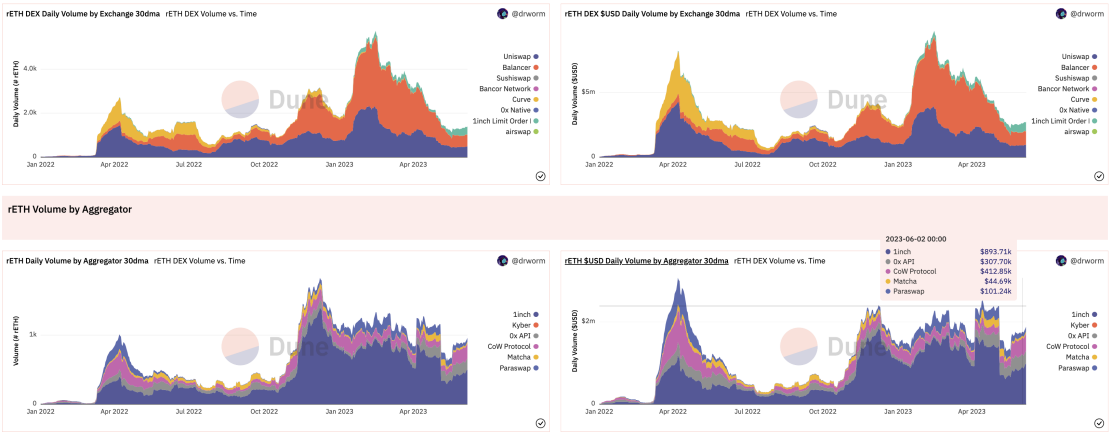


Figure 92: Dune Analytics Rocket Pool rETH DEX graphs by @drworm (7 June 2023)

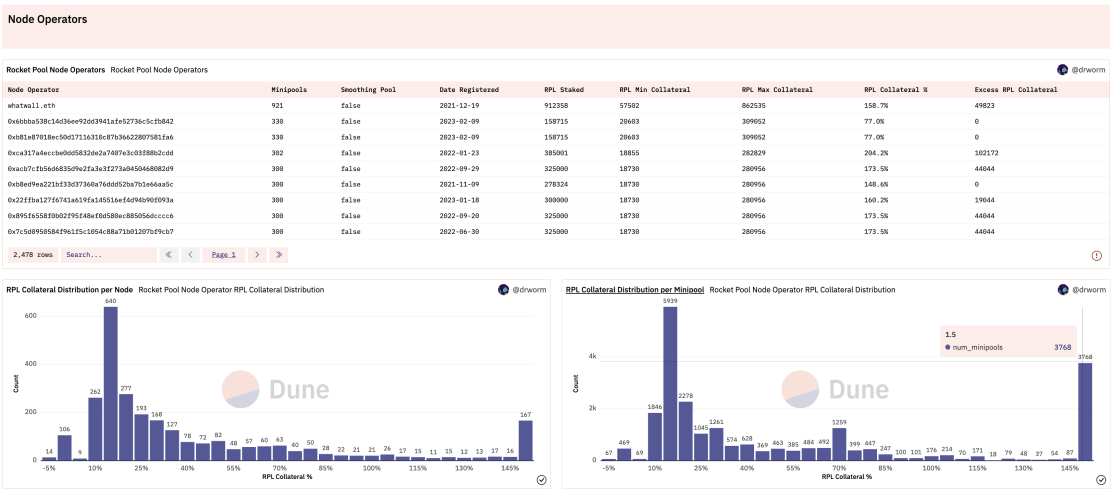


Figure 93: Dune Analytics Rocket Pool node operators by @drworm (7 June 2023)

Figure 94: Dune Analytics Rocket Pool oDAO-Reported RPL Price/RPL Staked by @drworm (7 June 2023)

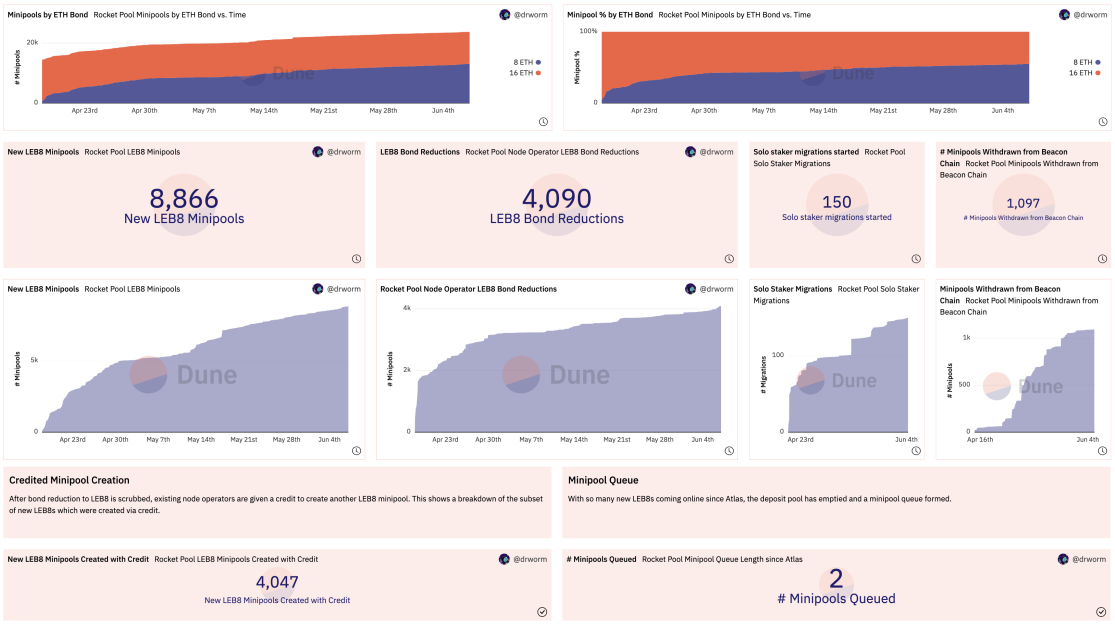


Figure 95: Dune Analytics Rocket Pool Minipools by @drworm (7 June 2023)

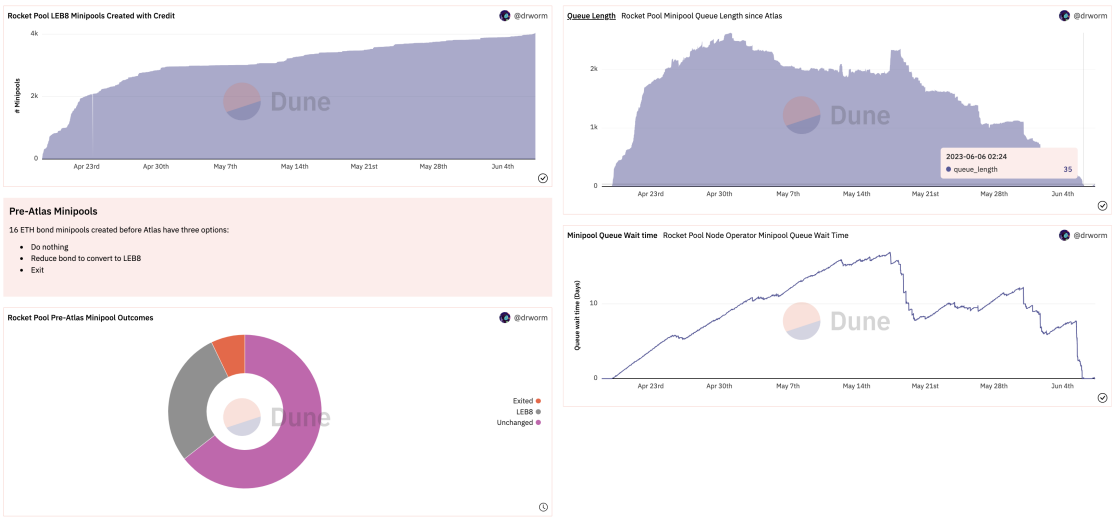


Figure 96: Dune Analytics Rocket Pool Rocket Pool Minipools by @drworm (7 June 2023)

ETH burnt

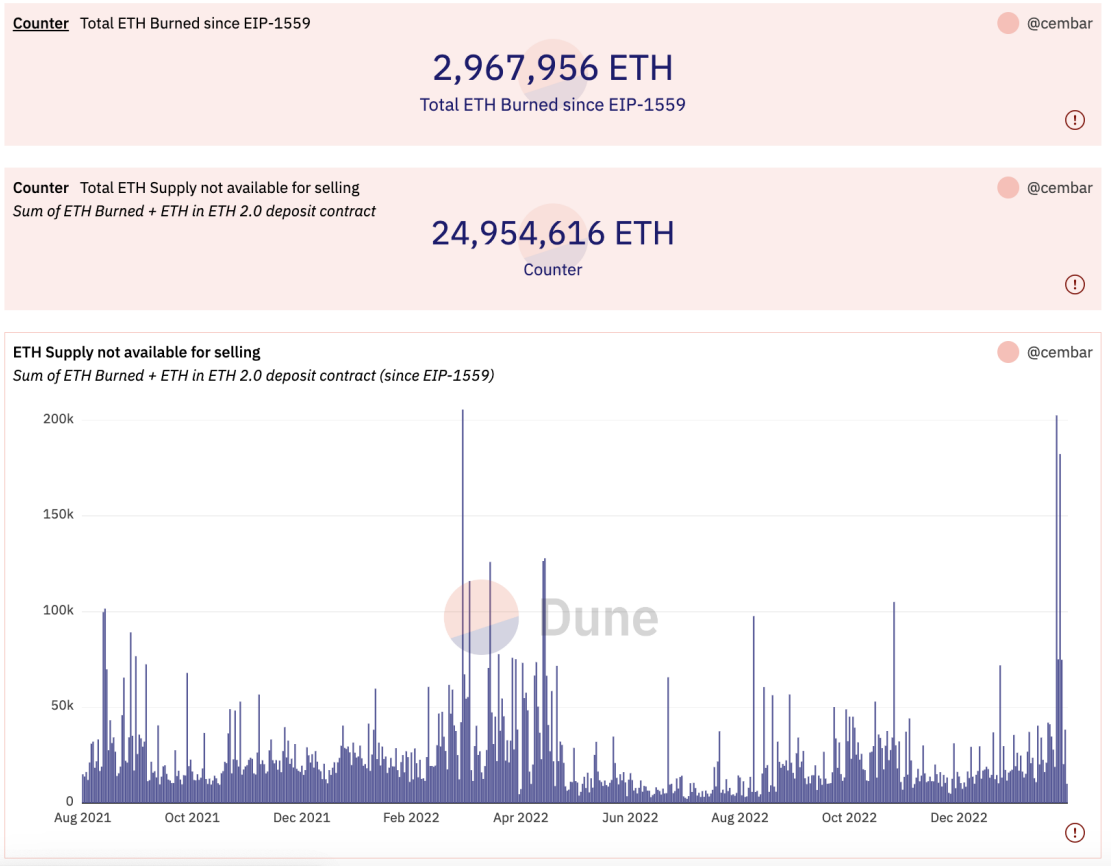


Figure 97: Dune Analytics of ETH not available for selling, i.e. ETH is burnt or staked by @cembar (6 June 2023)

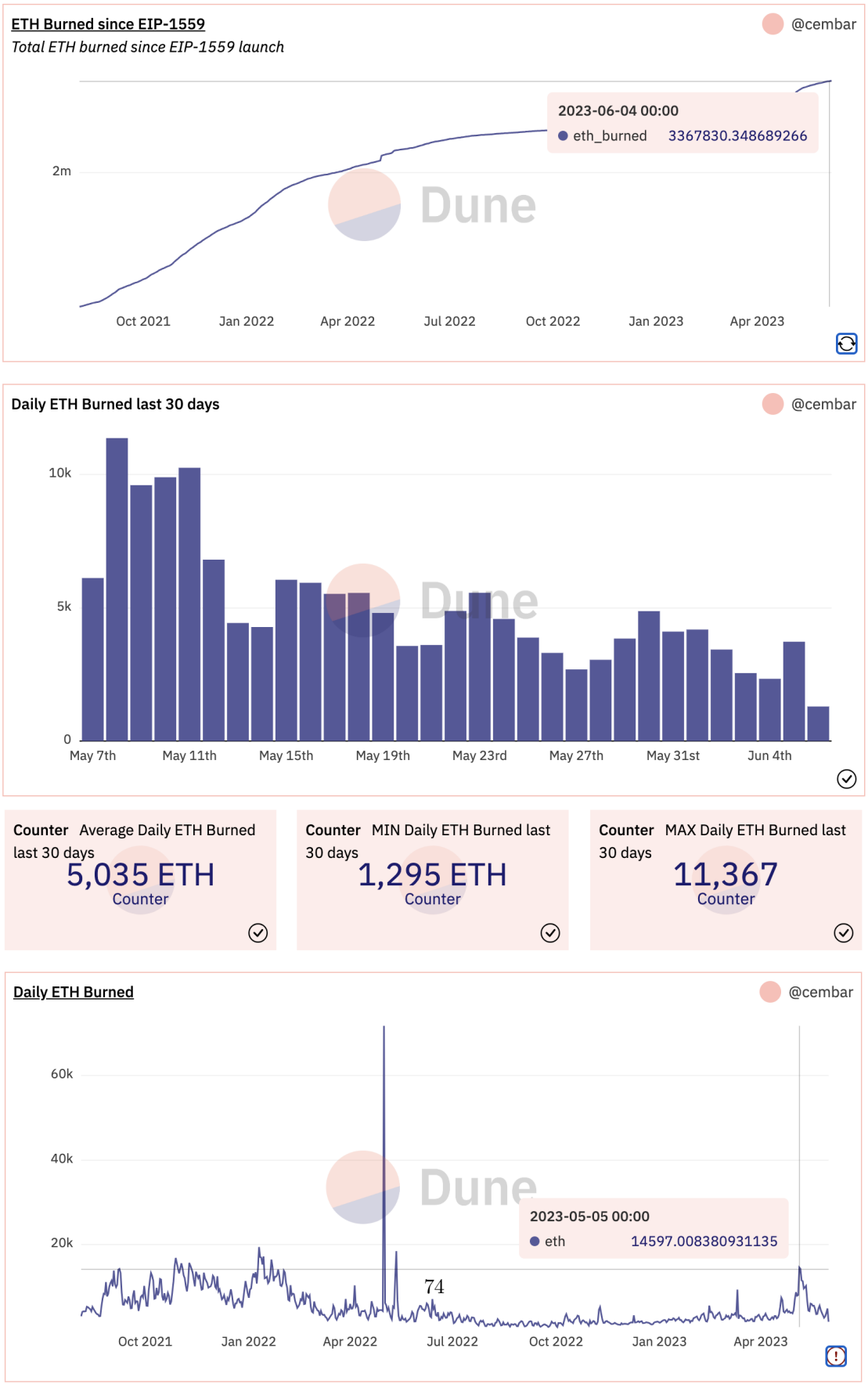


Figure 98: Dune Analytics of total and daily ETH burnt by @cembar (6 June 2023)

Beaconcha.in

The website provides the ability to search using a variety of fields, including a public key, block number, block graffiti, proposer, slot, and epoch. Apart from the extensive information and visualisations shown here, there are several other

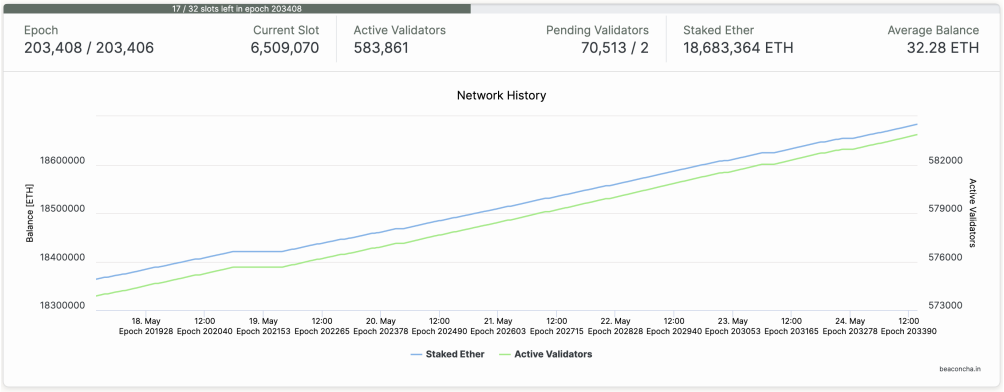


Figure 99: Homepage of beaconcha.in showing a progress line of the slots in the current epoch with a graph of total staked Ether and active validators over the last week, from Beaconcha.in (24 May 2023)

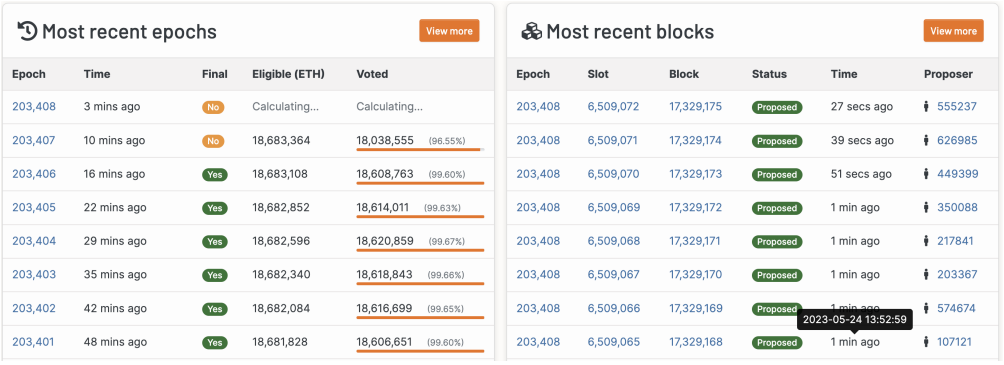
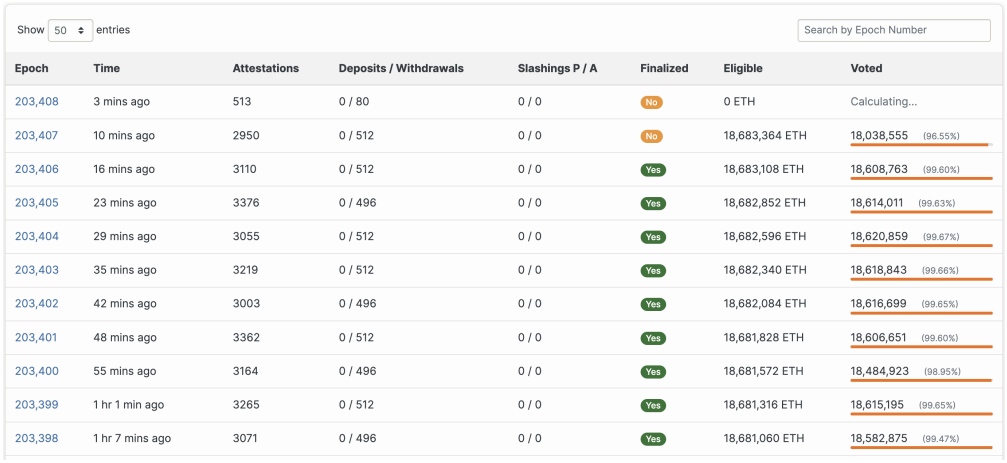


Figure 100: Homepage of beaconcha.in showing the most recent epochs and blocks, from Beaconcha.in (24 May 2023)

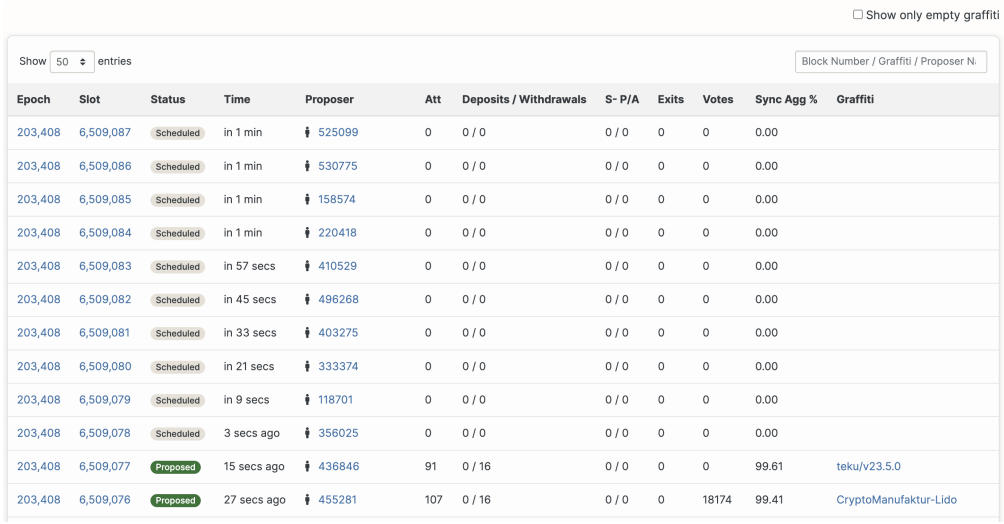
Blockchain data



Show 50 entries — Search by Epoch Number

Epoch	Time	Attestations	Deposits / Withdrawals	Slashings P / A	Finalized	Eligible	Voted
203,408	3 mins ago	513	0 / 80	0 / 0	No	0 ETH	Calculating...
203,407	10 mins ago	2950	0 / 512	0 / 0	No	18,683,364 ETH	18,038,555 (96.55%)
203,406	16 mins ago	3110	0 / 512	0 / 0	Yes	18,683,108 ETH	18,608,763 (99.60%)
203,405	23 mins ago	3376	0 / 496	0 / 0	Yes	18,682,852 ETH	18,614,011 (99.63%)
203,404	29 mins ago	3055	0 / 512	0 / 0	Yes	18,682,596 ETH	18,620,859 (99.67%)
203,403	35 mins ago	3219	0 / 512	0 / 0	Yes	18,682,340 ETH	18,618,843 (99.66%)
203,402	42 mins ago	3003	0 / 496	0 / 0	Yes	18,682,084 ETH	18,616,699 (99.65%)
203,401	48 mins ago	3362	0 / 512	0 / 0	Yes	18,681,828 ETH	18,606,651 (99.60%)
203,400	55 mins ago	3164	0 / 496	0 / 0	Yes	18,681,572 ETH	18,484,923 (98.95%)
203,399	1 hr 1 min ago	3265	0 / 512	0 / 0	Yes	18,681,316 ETH	18,615,195 (99.65%)
203,398	1 hr 7 mins ago	3071	0 / 496	0 / 0	Yes	18,681,060 ETH	18,582,875 (99.47%)

Figure 101: Detailed information for epochs with the ability to search for a specific epoch, from Beaconcha.in (24 May 2023)



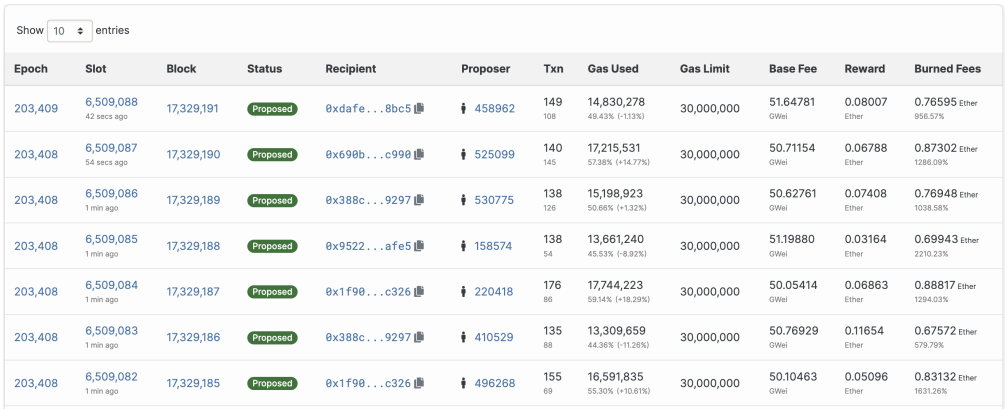
Show only empty graffiti

Show 50 entries

Block Number / Graffiti / Proposer N

Epoch	Slot	Status	Time	Proposer	Att	Deposits / Withdrawals	S- P/A	Exits	Votes	Sync Agg %	Graffiti
203,408	6,509,087	Scheduled	in 1 min	525099	0	0 / 0	0 / 0	0	0	0.00	
203,408	6,509,086	Scheduled	in 1 min	530775	0	0 / 0	0 / 0	0	0	0.00	
203,408	6,509,085	Scheduled	in 1 min	158574	0	0 / 0	0 / 0	0	0	0.00	
203,408	6,509,084	Scheduled	in 1 min	220418	0	0 / 0	0 / 0	0	0	0.00	
203,408	6,509,083	Scheduled	in 57 secs	410529	0	0 / 0	0 / 0	0	0	0.00	
203,408	6,509,082	Scheduled	in 45 secs	496268	0	0 / 0	0 / 0	0	0	0.00	
203,408	6,509,081	Scheduled	in 33 secs	403275	0	0 / 0	0 / 0	0	0	0.00	
203,408	6,509,080	Scheduled	in 21 secs	333374	0	0 / 0	0 / 0	0	0	0.00	
203,408	6,509,079	Scheduled	in 9 secs	118701	0	0 / 0	0 / 0	0	0	0.00	
203,408	6,509,078	Scheduled	3 secs ago	356025	0	0 / 0	0 / 0	0	0	0.00	
203,408	6,509,077	Proposed	15 secs ago	436846	91	0 / 16	0 / 0	0	0	99.61	teku/v23.5.0
203,408	6,509,076	Proposed	27 secs ago	455281	107	0 / 16	0 / 0	0	18174	99.41	CryptoManufaktur-Lido

Figure 102: Detailed information for slots with the ability to search by block number, graffiti or proposer number, from Beaconcha.in (24 May 2023)



Show 10 entries

Epoch	Slot	Block	Status	Recipient	Proposer	Txn	Gas Used	Gas Limit	Base Fee	Reward	Burned Fees
203,409	6,509,088 42 secs ago	17,329,191	Proposed	0xdafe...8bc5	458962	149 108	14,830,278 49.43% (-1.13%)	30,000,000	51.64781 GWei	0.08007 Ether	0.76595 Ether 956.57%
203,408	6,509,087 54 secs ago	17,329,190	Proposed	0x690b...c990	525099	140 145	17,215,531 57.38% (+14.77%)	30,000,000	50.71154 GWei	0.06788 Ether	0.87302 Ether 1286.09%
203,408	6,509,086 1 min ago	17,329,189	Proposed	0x388c...9297	530775	138 126	15,198,923 50.66% (+1.32%)	30,000,000	50.62761 GWei	0.07408 Ether	0.76948 Ether 1038.58%
203,408	6,509,085 1 min ago	17,329,188	Proposed	0x9522...afe5	158574	138 54	13,661,240 45.53% (-8.92%)	30,000,000	51.19880 GWei	0.03164 Ether	0.69943 Ether 2210.23%
203,408	6,509,084 1 min ago	17,329,187	Proposed	0x1f90...c326	220418	176 86	17,744,223 59.14% (+18.29%)	30,000,000	50.05414 GWei	0.06863 Ether	0.88817 Ether 1294.03%
203,408	6,509,083 1 min ago	17,329,186	Proposed	0x388c...9297	410529	135 88	13,309,659 44.36% (-11.26%)	30,000,000	50.76929 GWei	0.11654 Ether	0.67572 Ether 579.79%
203,408	6,509,082 1 min ago	17,329,185	Proposed	0x1f90...c326	496268	155 69	16,591,835 55.30% (+10.61%)	30,000,000	50.10463 GWei	0.05096 Ether	0.83132 Ether 1631.26%

Figure 103: Detailed information of all blocks, from Beaconcha.in (24 May 2023)

Tx Hash	Method	Block	Time	From	To	Value	Tx Fee
0x9b14…df1e	0×7316b024	17,329,196	28 secs ago	0xd985…bF59	0x0000…2683	0.00000000 Ether	0.01692128 Ether
0x9a7d…f667	execute	17,329,196	28 secs ago	0xbDb9…11D1	0xEf1c…BF6B	10 Ether	0.00686362 Ether
0xcfef…148e	0×8a56c398	17,329,196	28 secs ago	0xB722…11fb	0x0000…2683	0.00000000 Ether	0.20266461 Ether
0x36d6…7c5e	swapExactETHForTokensSupp...	17,329,196	28 secs ago	0x1e00…f2f8	Uniswap V2: Rou...	0.05 Ether	0.00898044 Ether
0xeb9c…1260	approve	17,329,196	28 secs ago	0x1e00…f2f8	0x916B…520e	0 Ether	0.00280960 Ether
0xb6f6…2fff	0×00000201	17,329,196	28 secs ago	0x27eb…C008	0xFd00…7AD7	0.00000000 Ether	0.01089586 Ether
0x1faa…26fc	exec	17,329,196	28 secs ago	0x620d…a4A1	0x3CAC…83b6	0 Ether	0.03407473 Ether
0x6835…54de	deposit	17,329,196	28 secs ago	0x46ba…F459	Wrapped Ether	1.6 Ether	0.00136990 Ether
0xd8d1…e8f9	withdraw	17,329,196	28 secs ago	0x96FA…E007	Wrapped Ether	0 Ether	0.00148918 Ether
0xbb24…9844	transfer	17,329,196	28 secs ago	0x6859…2092	Tether: USDT St...	0 Ether	0.00454948 Ether

Figure 104: Detailed information of all transactions, from Beaconcha.in (24 May 2023)

Show 25 entries Search:

Hash	From	To	Value	Gas Limit	Gas Price	Nonce
0xfecae…bdcee	0xAdf…a0c6	0xAdf…a0c6	0 Ether	21,000	99.97304 GWei	2
0x7a2d5…b2d4f	0x6E8…813e	0x6E8…813e	0 Ether	56,311	99.90639 GWei	24
0x79e0c…8a0fe	0x5f4…d2ED	0x5f4…d2ED	0 Ether	21,000	99.77602 GWei	5
0xfa912…a6451	0xC67…799A	0xC67…799A	0 Ether	51,594	99.73214 GWei	33
0xa3b34…c6532	0x7e2…c71e	0xBef…71c6	0 Ether	121,341	99.72739 GWei	124
0x85986…2a62f	0x997…0134	0x7D1…eBB0	0 Ether	48,416	99.58487 GWei	21
0x80085…bcef3	0x661…2863	0xC02…6Cc2	0 Ether	25,882	99.56017 GWei	71
0x3ee72…87789	0x266…4Ed7	0x266…4Ed7	0 Ether	21,000	99.55 GWei	24
0x0a6a5…2863a	0xCaA…f14e	0xC02…6Cc2	0.015 Ether	45,038	99.23455 GWei	6

Figure 105: Mempool transaction details, from Beaconcha.in (24 May 2023)

Validator data

All 712863

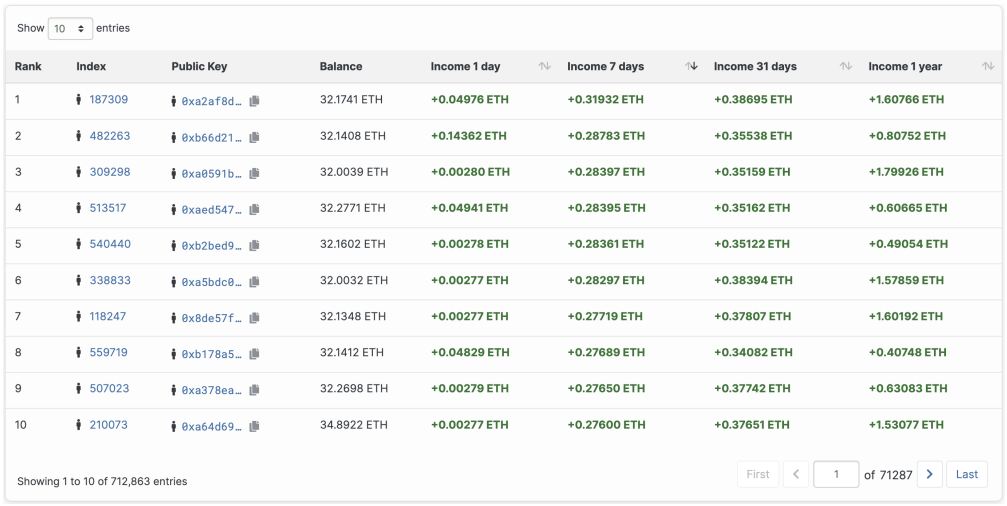
Public Key	Index	Balance	State	Activation	Exit	W/able
0×80000001...	8499 (101ca7)	36.4121 ETH (32.0 ETH)	Active	904 days 1 min ago (Epoch 0)	-	-
0×800003d8...	197823	32.0064 ETH (32.0 ETH)	Active	673 days 53 mins ago (Epoch 51,967)	-	-
0×800006d4...	347967	32.0031 ETH (32.0 ETH)	Active	401 days 9 hrs ago (Epoch 113,098)	-	-
0×80000821...	413630	32.0015 ETH (32.0 ETH)	Active	285 days 23 hrs ago (Epoch 139,059)	-	-
0×80000cdd...	162791	34.9332 ETH (32.0 ETH)	Active	712 days 4 mins ago (Epoch 43,209)	-	-
0×8000118f...	611152	32.0101 ETH (32.0 ETH)	Active	17 days 17 hrs ago (Epoch 199,419)	-	-
0×80002598...	665475	32.0000 ETH (32.0 ETH)	Pending	-	-	-
0×800026c3...	118493	0.0000 ETH (0.0 ETH)	Exited	771 days 13 hrs ago (Epoch 29,808)	24 days 20 hrs ago (Epoch 197,813)	23 days 17 hrs ago (Epoch 19
0×80002a23...	112948	32.0082 ETH (32.0 ETH)	Active	784 days 1 hr ago (Epoch 26,999)	-	-
0×80002b5a...	627027	32.0436 ETH (32.0 ETH)	Active	9 days 2 hrs ago (Epoch 201,358)	-	-

Figure 106: Overview of validators. Beaconcha.in (24 May 2023)

Show 10 entries

Slashed Validators	Slashed by	Age	Reason	Slot	Epoch
7506	296952	8 hrs 37 mins ago	Attestation Violation	6,506,530	203,329
26165	22260	10 days 13 hrs ago	Attestation Violation	6,433,214	201,037
48608	553505	11 days 17 hrs ago	Attestation Violation	6,424,518	200,766
48607	144422	11 days 20 hrs ago	Attestation Violation	6,423,764	200,742
48609	169630	11 days 20 hrs ago	Attestation Violation	6,423,751	200,742
459890	188013	41 days 11 mins ago	Attestation Violation	6,213,857	194,183
459098	501282	41 days 11 mins ago	Attestation Violation	6,213,856	194,183
459140	501282	41 days 11 mins ago	Attestation Violation	6,213,856	194,183

Figure 107: Slashed validators. Beaconcha.in (24 May 2023)



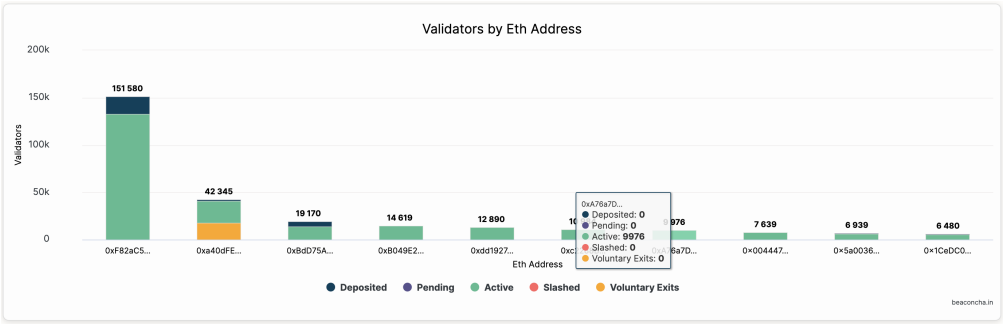
Show 10 entries

Rank	Index	Public Key	Balance	Income 1 day	Income 7 days	Income 31 days	Income 1 year
1	187309	0xa2af8d…	32.1741 ETH	+0.04976 ETH	+0.31932 ETH	+0.38695 ETH	+1.60766 ETH
2	482263	0xb66d21…	32.1408 ETH	+0.14362 ETH	+0.28783 ETH	+0.35538 ETH	+0.80752 ETH
3	309298	0xa0591b…	32.0039 ETH	+0.00280 ETH	+0.28397 ETH	+0.35159 ETH	+1.79926 ETH
4	513517	0xaed547…	32.2771 ETH	+0.04941 ETH	+0.28395 ETH	+0.35162 ETH	+0.60665 ETH
5	540440	0xb2bed9…	32.1602 ETH	+0.00278 ETH	+0.28361 ETH	+0.35122 ETH	+0.49054 ETH
6	338833	0xa5bdc0…	32.0032 ETH	+0.00277 ETH	+0.28297 ETH	+0.38394 ETH	+1.57859 ETH
7	118247	0x8de57f…	32.1348 ETH	+0.00277 ETH	+0.27719 ETH	+0.37807 ETH	+1.60192 ETH
8	559719	0xb178a5…	32.1412 ETH	+0.04829 ETH	+0.27689 ETH	+0.34082 ETH	+0.40748 ETH
9	507023	0xa378ea…	32.2698 ETH	+0.00279 ETH	+0.27650 ETH	+0.37742 ETH	+0.63083 ETH
10	210073	0xa64d69…	34.8922 ETH	+0.00277 ETH	+0.27600 ETH	+0.37651 ETH	+1.53077 ETH

Showing 1 to 10 of 712,863 entries

First 1 of 71287 Last

Figure 108: Validator leaderboard - default listing order is by 7day income, but it is possible to display the order by income based on 1day, 31 days or 1 year. Beaconcha.in (24 May 2023)



This table displays the leaderboard for deposits made by Ethereum Addresses to the Deposit Contract

Show 10 entries

Address

Address	Total Deposited	Valid	Invalid	Pen	Att	Sla	Ex	Tot
0xF82aC5…	4,850,560 ETH	151580	0	0	133098	11	0	150926
0xa40dFE…	1,355,040 ETH	42345	0	0	23014	0	17612	42331
0xBdD75A…	613,440 ETH	19170	0	0	14171	0	0	19170
0xB049E2…	467,808 ETH	14619	0	0	14619	0	0	14619
0xdd1927…	412,480 ETH	12890	0	0	12890	0	0	12890
0xc2288B…	351,488 ETH	10984	0	0	10981	0	0	10981
0xA76a7D…	319,232 ETH	9976	0	0	9976	0	0	9976
0x004447…	244,448 ETH	7639	0	0	7639	0	0	7639
0x5a0036…	221,889 ETH	6939	0	0	5498	0	334	6880
0x1CeDC0…	207,360 ETH	6480	0	0	5200	0	0	6480

Showing 1 to 10 of 105,551 entries

First 1 of 10556 Last

Figure 109: Leaderboard for deposits made by Ethereum addresses to the deposit contract - default order is by total amount deposited, but it is possible to display the order using any of the other columns shown in the table. Beaconcha.in (24 May 2023)

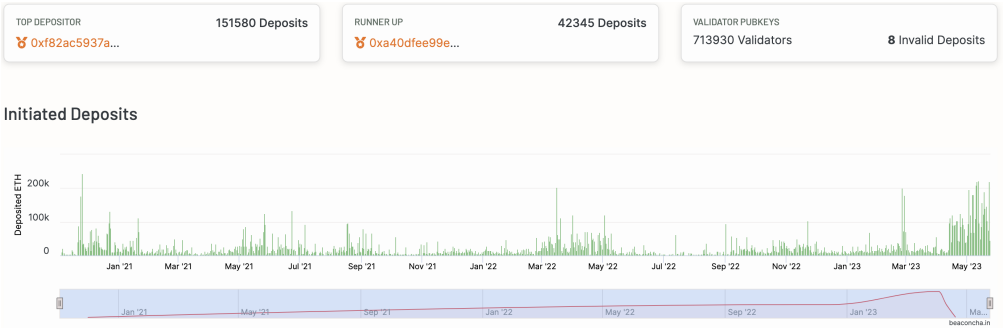


Figure 110: Visualisation of deposits since beaconchain genesis. Beaconcha.in (24 May 2023)

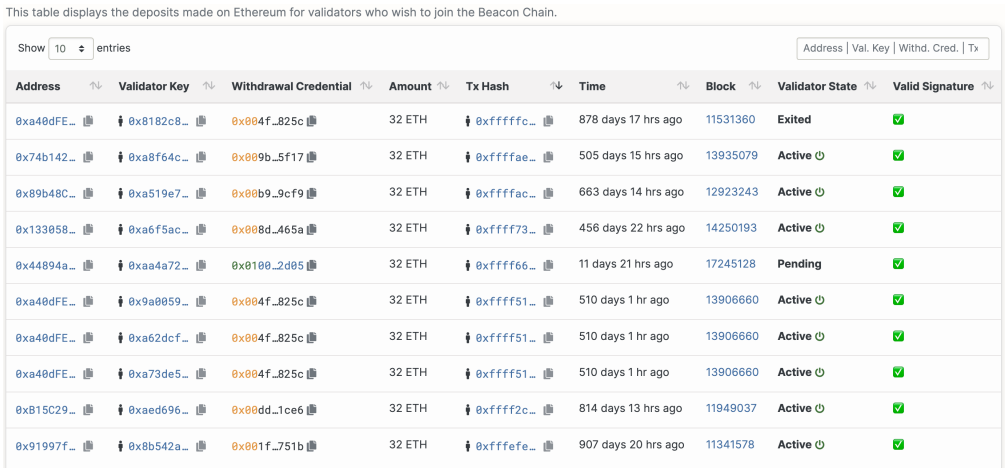
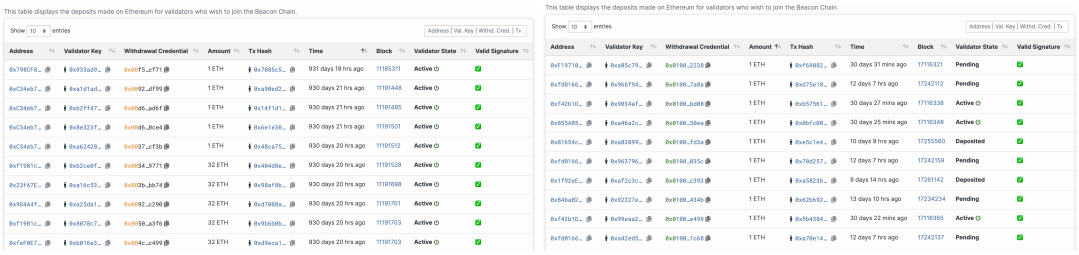


Figure 111: Initiated deposits: table of the deposits made by validators wishing to join the beaconchain.. Beaconcha.in (24 May 2023)



(a) (b)

Figure 112: Table of deposits ordered by time (a) and by amount deposited (b). Beaconcha.in (24 May 2023)

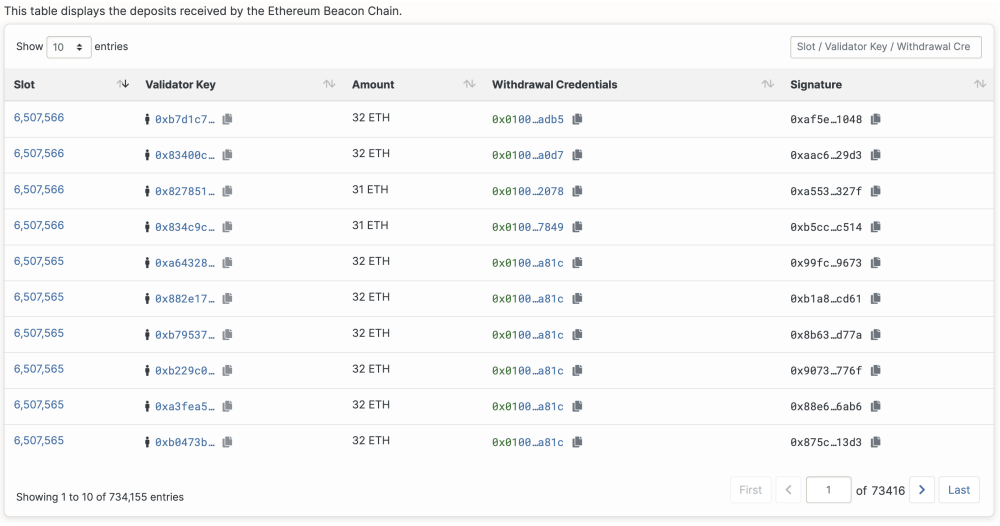


Figure 113: Included deposits: table of the deposits received by the beaconchain. Beaconcha.in (24 May 2023)

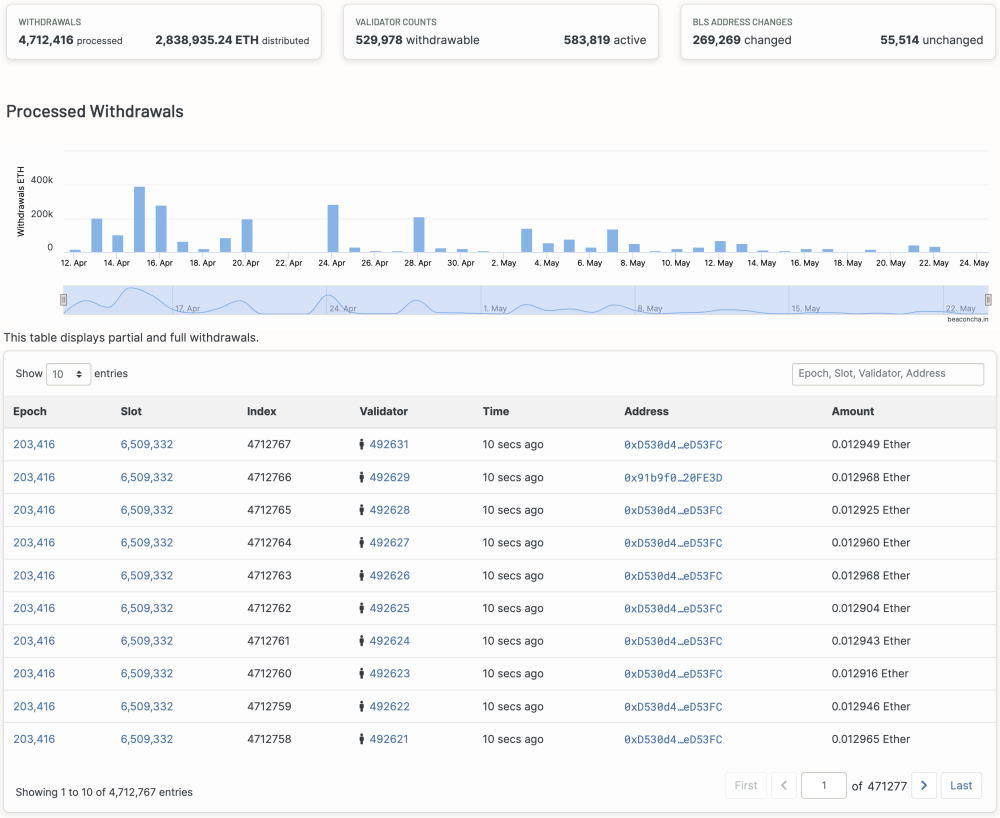


Figure 114: Histogram and table of withdrawals. Beaconcha.in (24 May 2023)

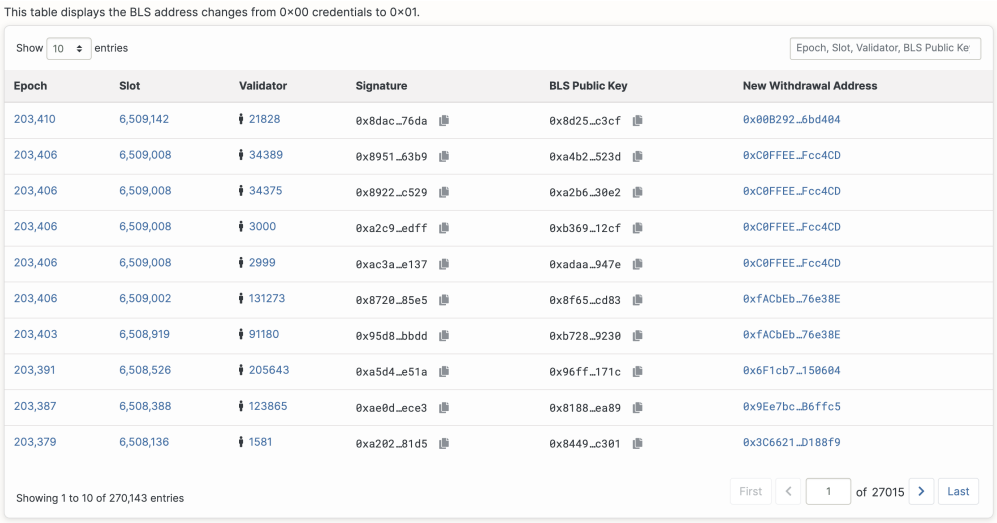


Figure 115: Table displaying the BLS address changes from 0x00 credentials to 0x01. Beaconcha.in (24 May 2023)

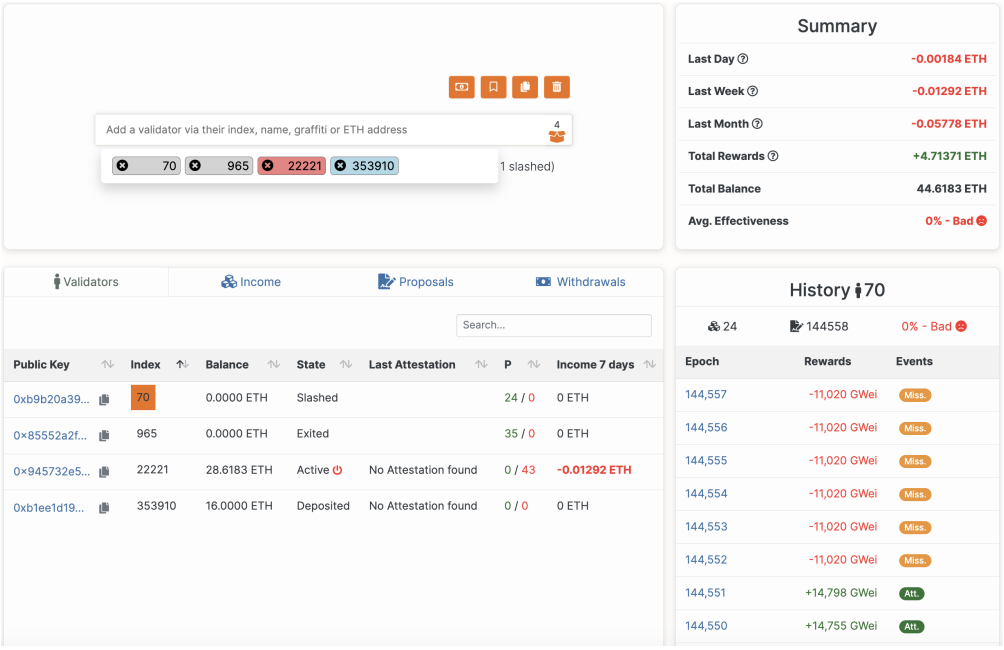


Figure 116: Validator dashboard - add the validators of interest to the search bar. In this example we added three validators: one active, one voluntary exited and one slashed validator. Beaconcha.in (24 May 2023)

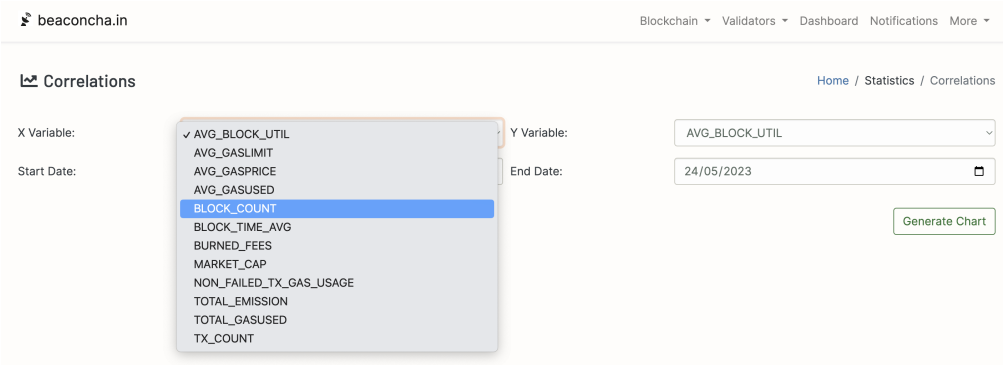
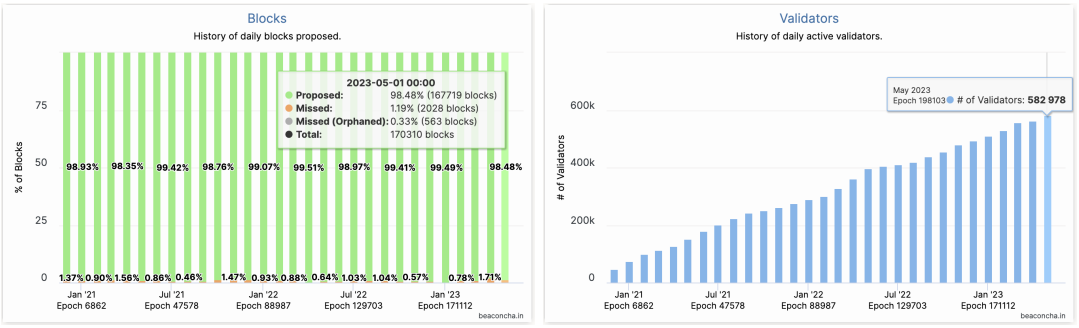


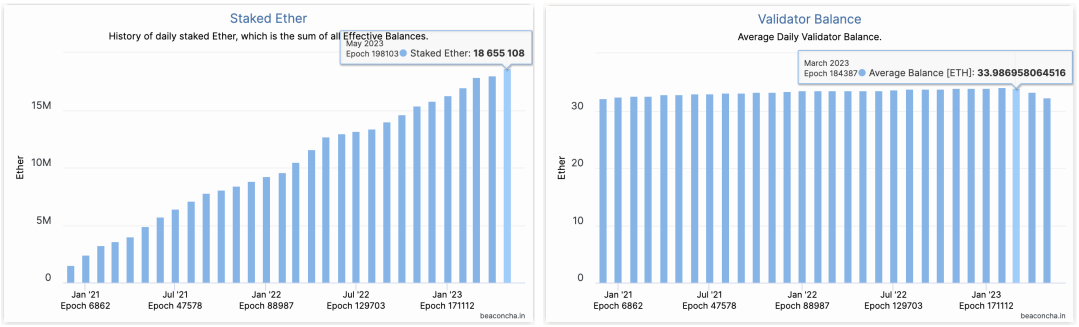
Figure 117: It is possible to generate correlation visualisations between several variables. Beaconcha.in (24 May 2023)

Consensus Layer Charts



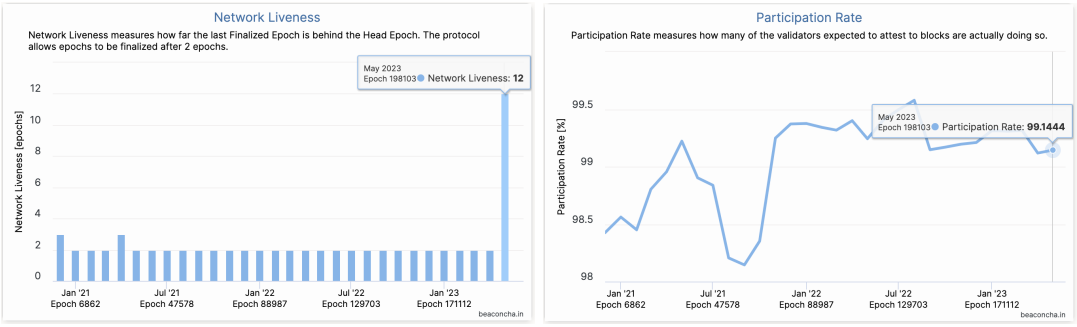
(a) (b)

Figure 118: History of daily blocks proposed (a) and daily active validators (b) from Beaconcha.in (24 May 2023)



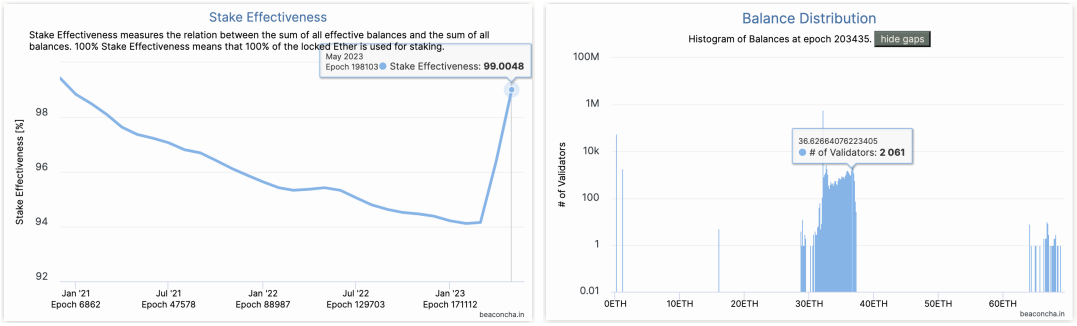
(a) (b)

Figure 119: History of daily staked Ether (sum of all effective balances) (a) and average daily validator balance (b) from Beaconcha.in (24 May 2023)



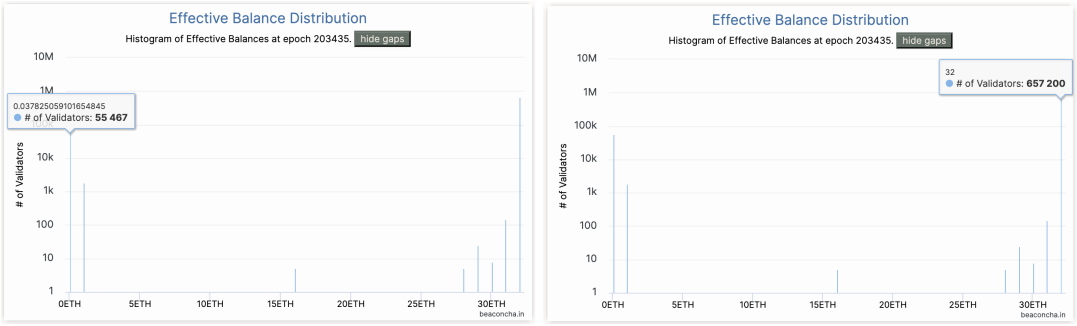
(a) (b)

Figure 120: Network liveness (measures how far the last finalised epoch is behind the head epoch. The protocol allows epochs to be finalised after 2 epochs) (a) and participation rate (measures how many of the validators expected to attest to blocks are actually doing so) (b) from Beaconcha.in (24 May 2023)



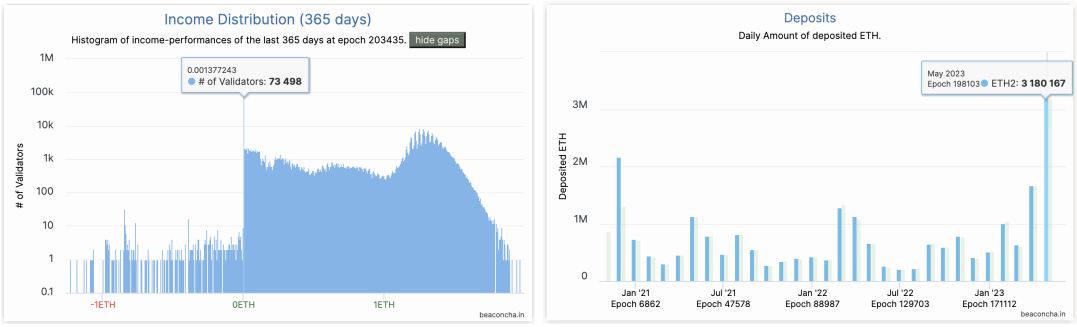
(a) (b)

Figure 121: Stake effectiveness (measures the relation between the sum if all effective balances and the sum of all balances. 100% stake effectiveness means that 100% of the locked ETH is used for staking) (a) and balance distribution (b) from Beaconcha.in (24 May 2023)



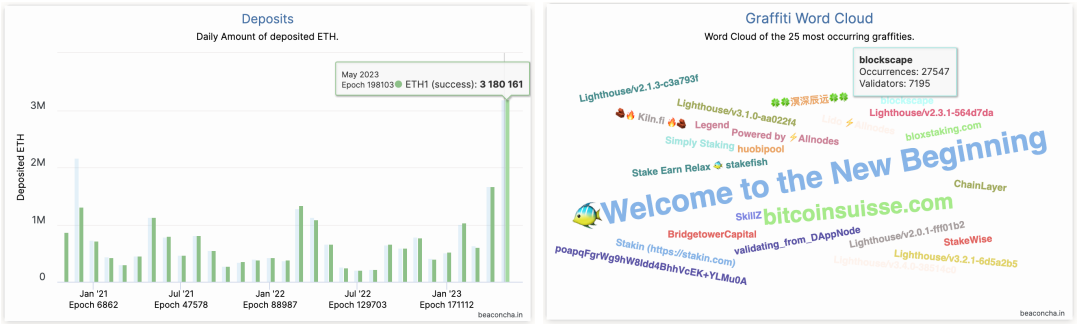
(a) (b)

Figure 122: Effective balance distribution showing information on the lowest balance - 0.04ETH (a) and for 32 ETH (b) from Beaconcha.in (24 May 2023)



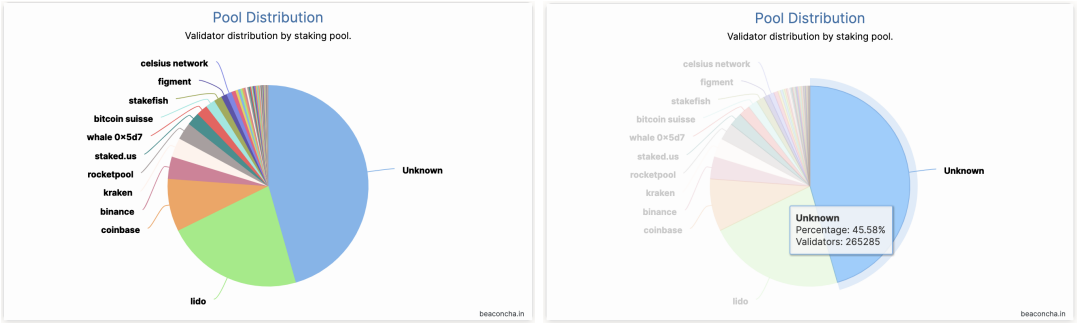
(a) (b)

Figure 123: Income distribution for the last 365 days (a) and Daily amount of deposited ETH on the consensus layer (b) from Beaconcha.in (24 May 2023)



(a) (b)

Figure 124: Daily amount of deposited ETH on the execution layer (a) and a graffiti word cloud of the 25 most occurring graffities (b) from Beaconcha.in (24 May 2023)

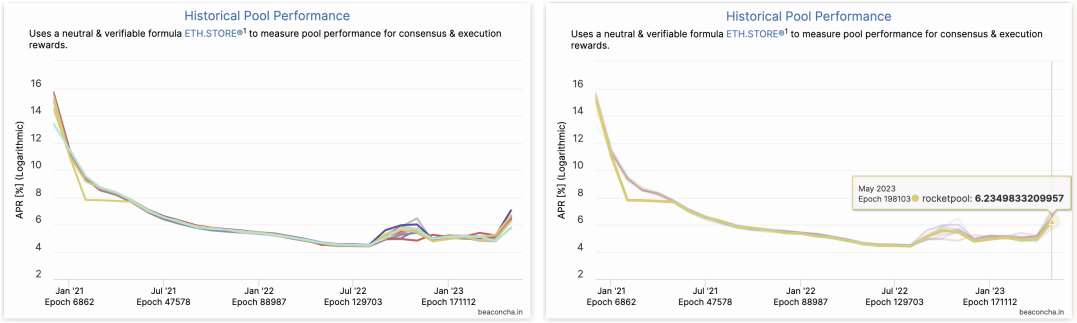


(a) (b)

Figure 125: Validator distribution by staking pool (a) and honing in on the proportion of validators not allocated to a known staking pool (b) from Beaconcha.in (24 May 2023)

(a) (b)

Figure 126: Validator distribution by staking pool showing the Lido pool (a) and Rocketpool (b) from Beaconcha.in (24 May 2023)



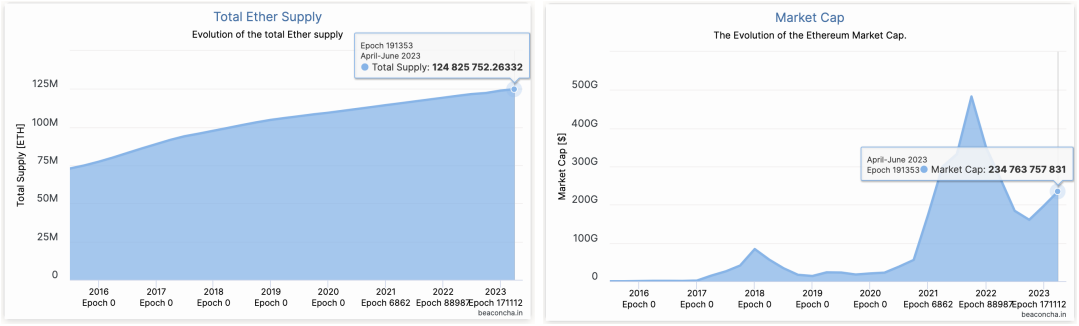
(a) (b)

Figure 127: Historical pool performance (a) and honing in on Rocketpool preformance (b) from Beaconcha.in (24 May 2023)

(a) (b)

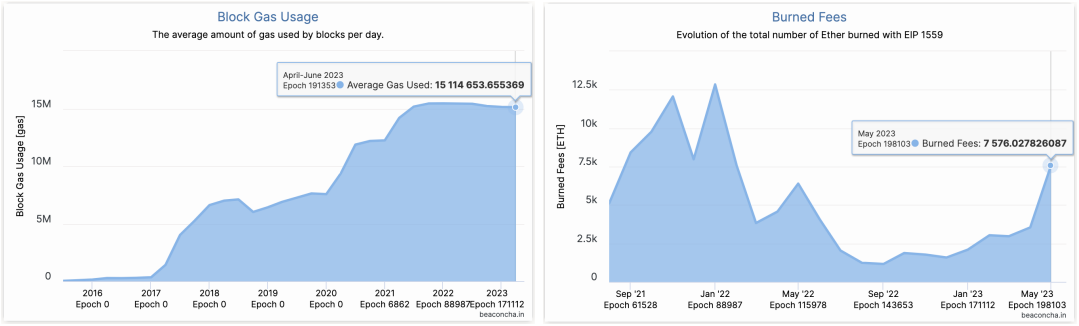
Figure 128: Daily amounts of withdrawals (a) and slot visualisation (click on the diagram for more detail) (b) from Beaconcha.in (24 May 2023)

Execution layer charts



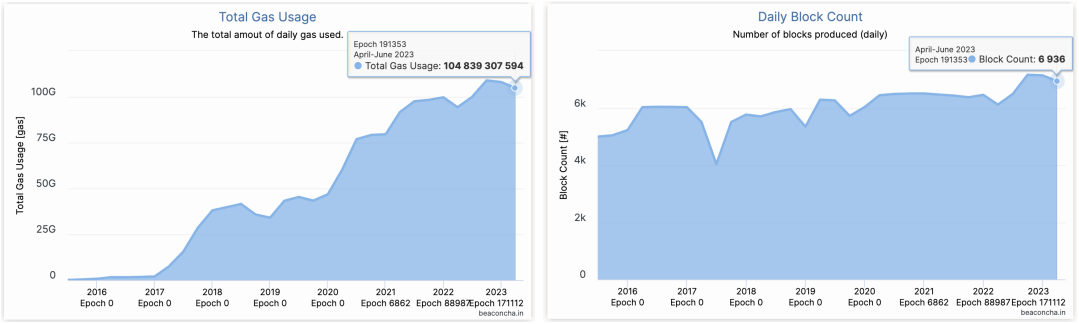
(a) (b)

Figure 129: Evolution of total ether supply (a) and of the Ethereum market capitilisation (b) from Beaconcha.in (24 May 2023)



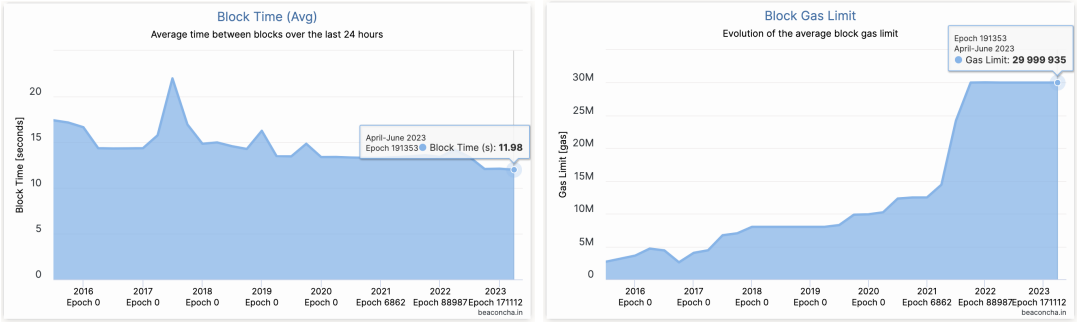
(a) (b)

Figure 130: The average amount of gas used by blocks per day (a) and the evolution of the total amount of Ether burned with EIP1559 (b) from Beaconcha.in (24 May 2023)



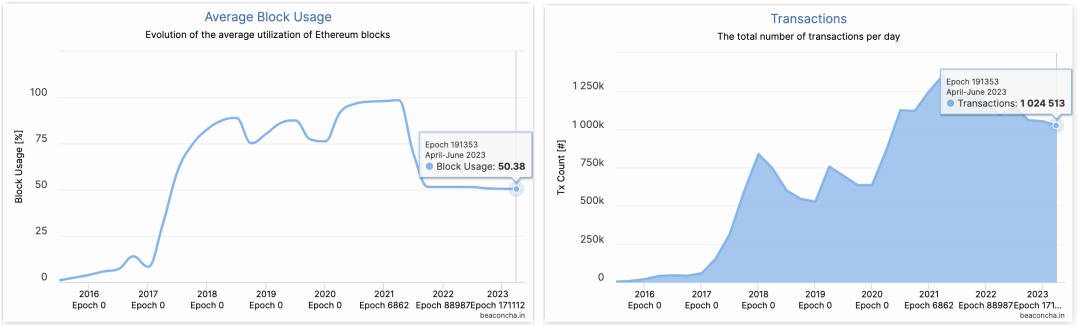
(a) (b)

Figure 131: The daily total amount of gas used (a) and the number of blocks produced daily (b) from Beaconcha.in (24 May 2023)



(a) (b)

Figure 132: Average time between blocks over the last 24 hours (a) and the evolution of the average block gas limit (b) from Beaconcha.in (24 May 2023)



(a) (b)

Figure 133: Evolution of the average utilisation of Ethereum blocks (a) and the total number of transactions per day (b) from Beaconcha.in (24 May 2023)

Mevboost.pics

General Dashboard

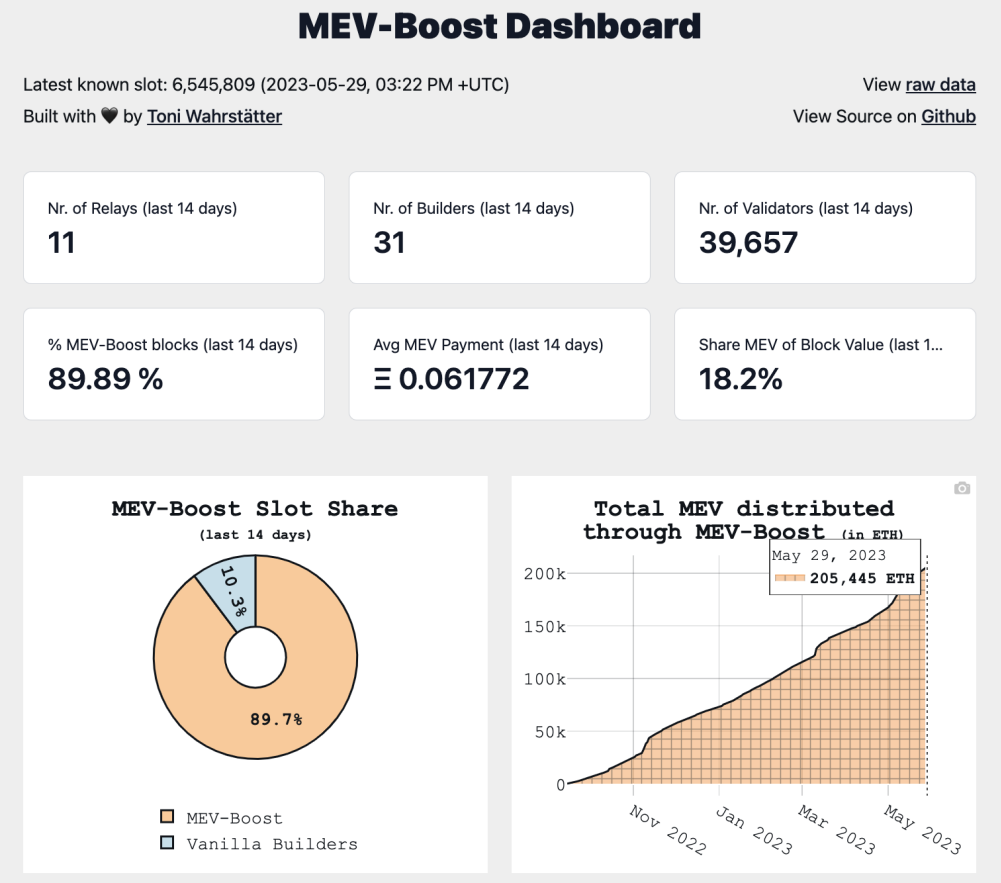


Figure 134: General Dashboard - summary statistics. Mevboost.pics.(29 May 2023)

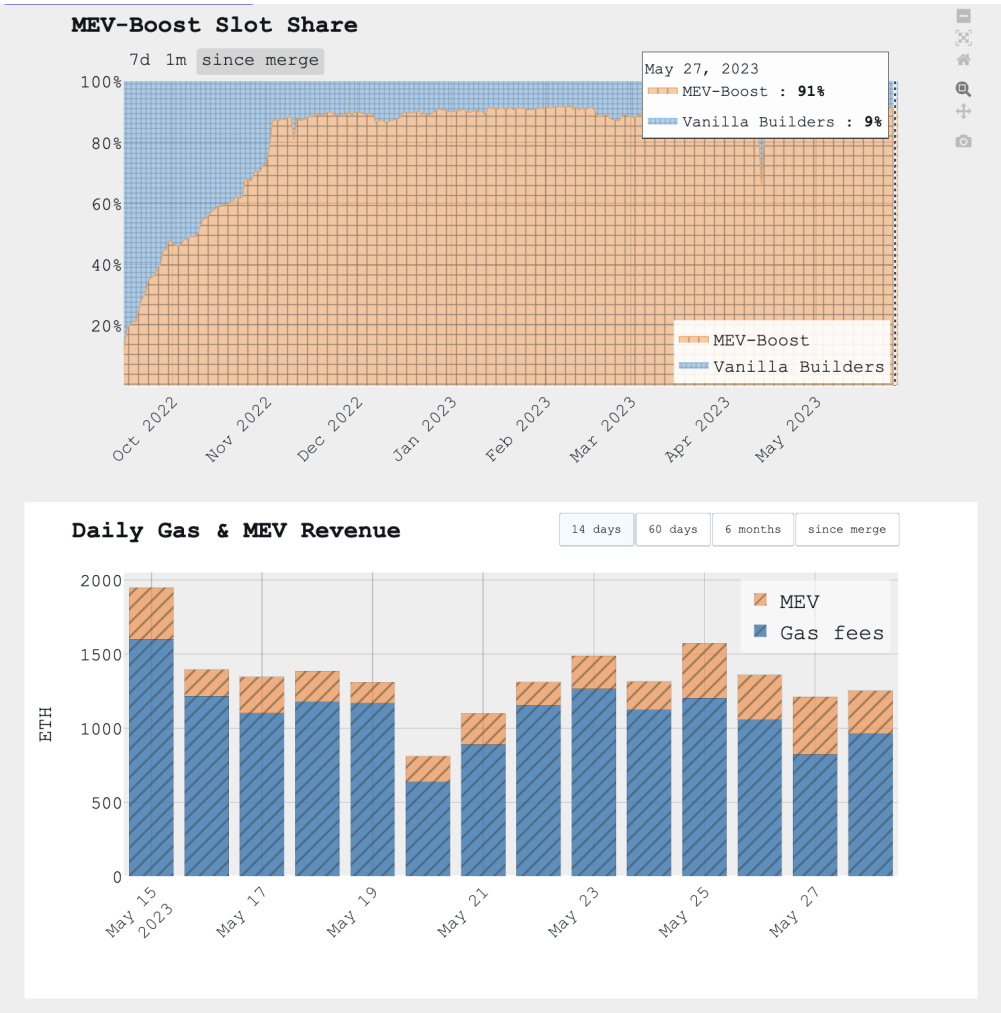


Figure 135: General Dashboard - slot share, daily gas and MEV revenue with the option of choosing different time periods. Mevboost.pics.(29 May 2023)

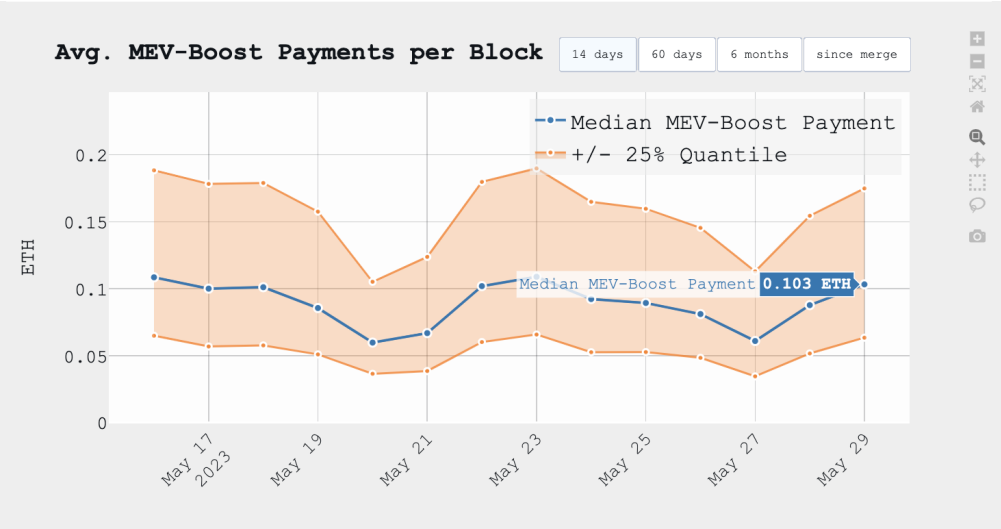


Figure 136: General Dashboard - Average MEV-Boost payments per block - choose between 14 days, 60 days, 6 months or since the merge. Mevboost.pics.(29 May 2023)

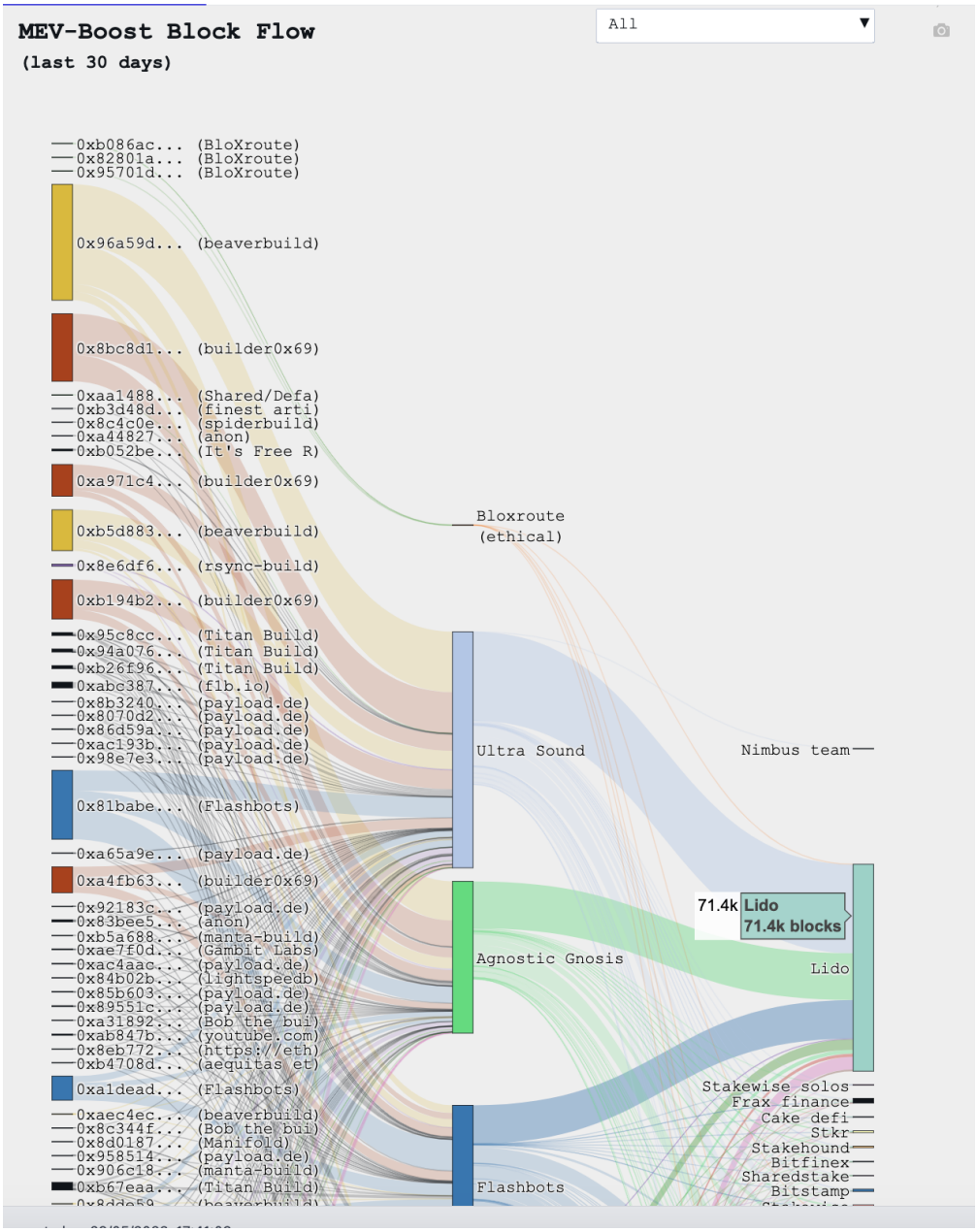


Figure 137: General Dashboard - MEV-Boost block flow. Select to display all builders, only builders active in the past 7 days, excluding small builders, or choose a builder from the available list. Mevboost.pics.(29 May 2023)

Relays Dashboard

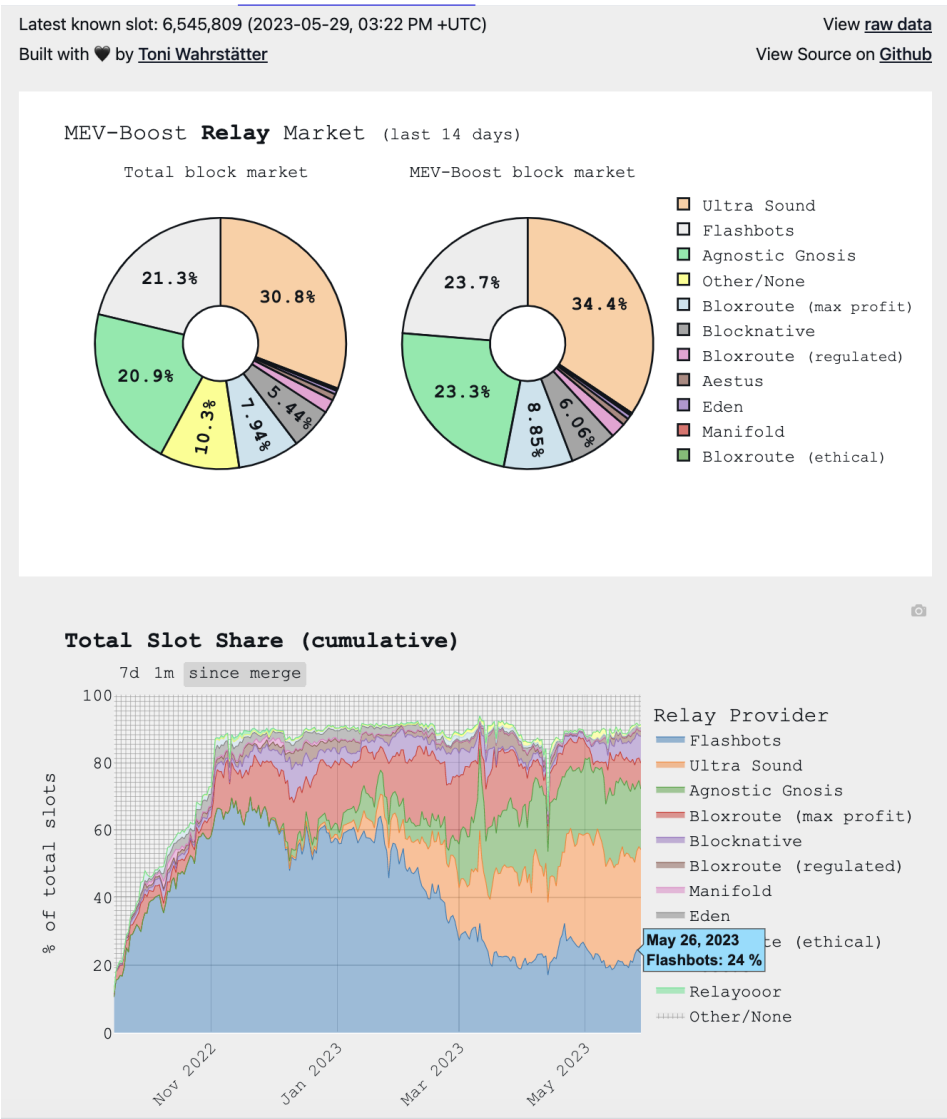


Figure 138: Relay Dashboard - MEV-Boost relay market (last 14 days) and total cumulative slot share (select from time ranges: 7 days, 1 month, since merge). Mevboost.pics.(29 May 2023)

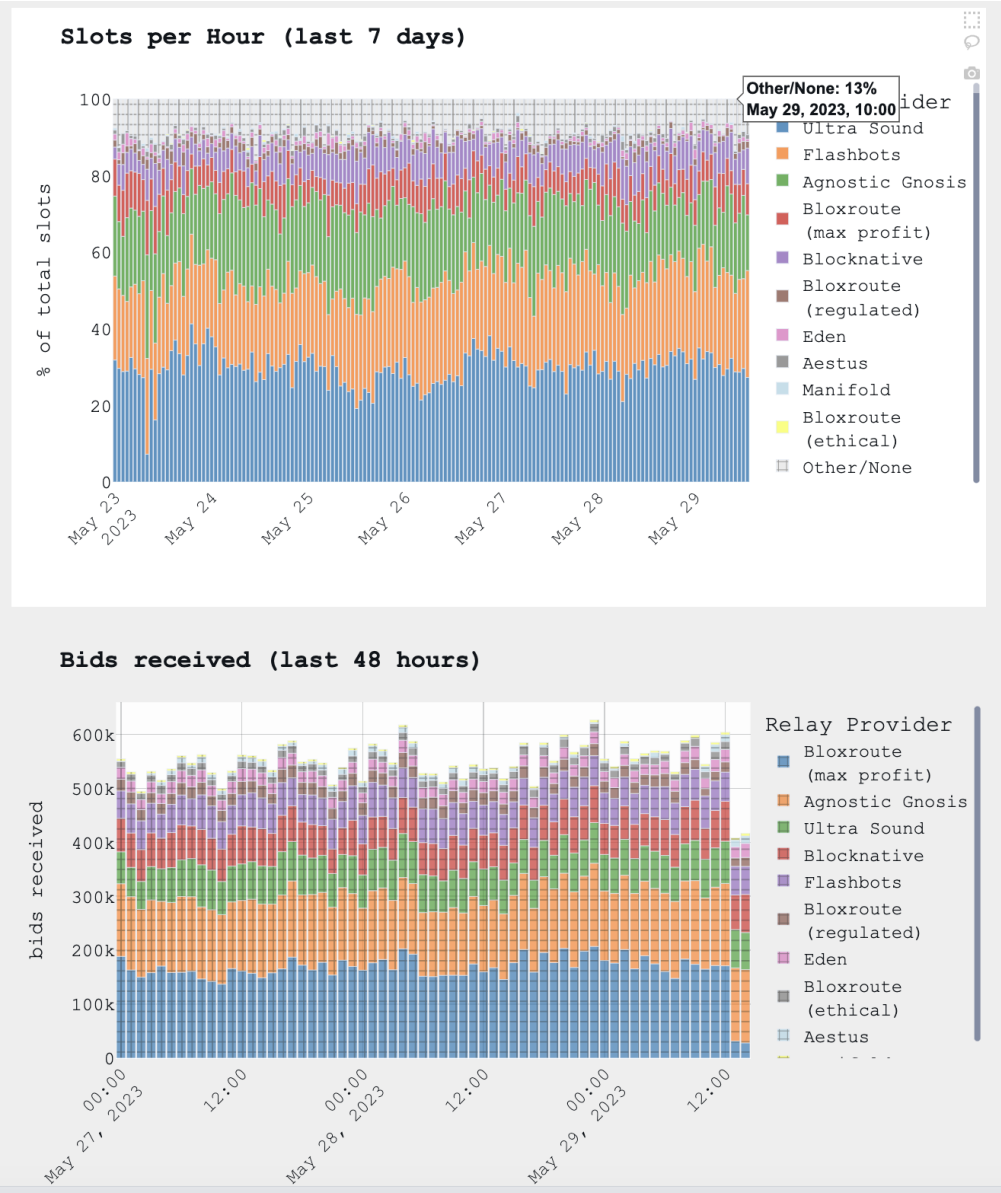


Figure 139: Relay Dashboard - Slots per hour (last 7 days) and bids received (last 48 hours). Mevboost.pics.(29 May 2023)

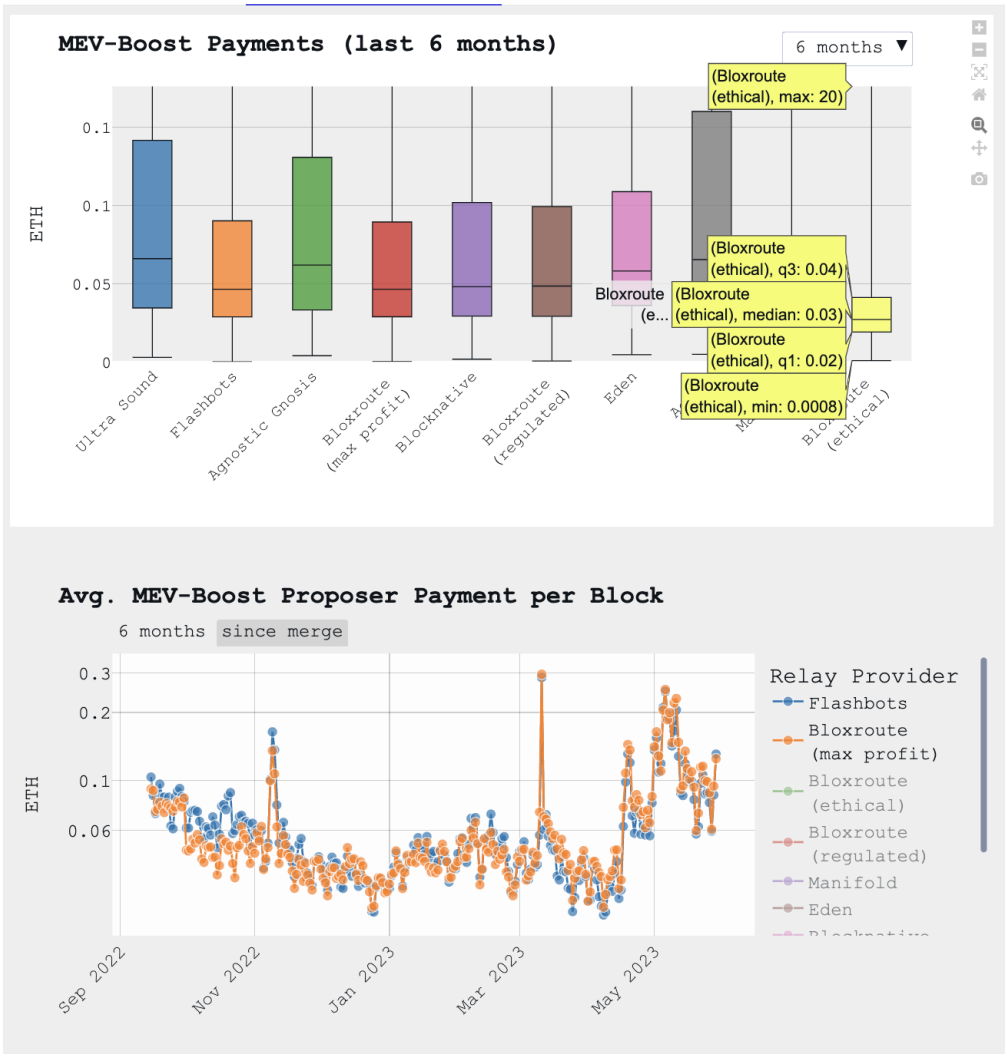


Figure 140: Relay Dashboard - MEV-Boost payments (select from last 48 hours, 7 days, 30 days or 6 months) and average MEV-Boost proposer payment per block (either for the last 6 months or since the merge). Mevboost.pics.(29 May 2023)

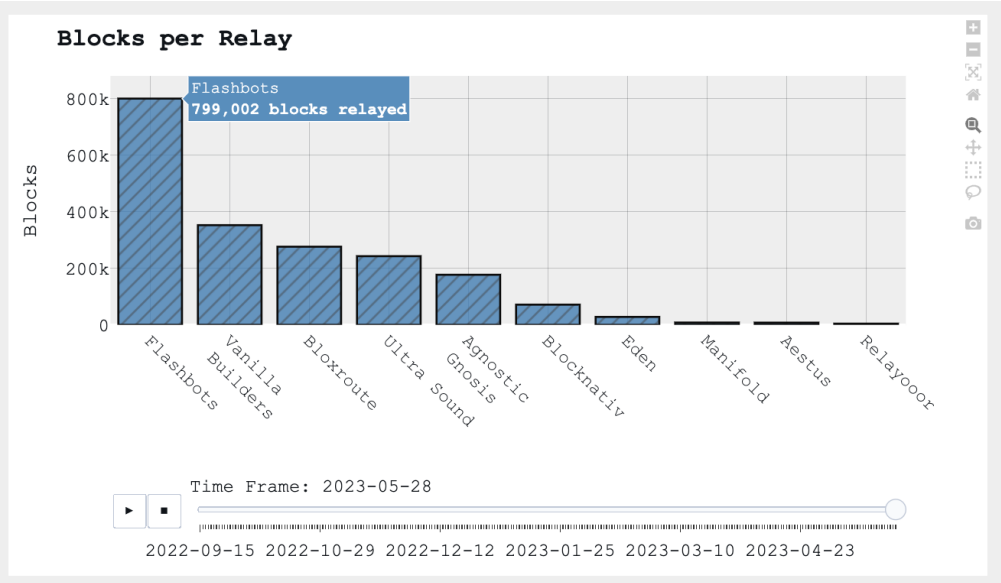


Figure 141: Blocks per relay. Press play to see the visualisation of the blocks per relayer change over time. Mevboost.pics.(29 May 2023)

Builders Dashboard

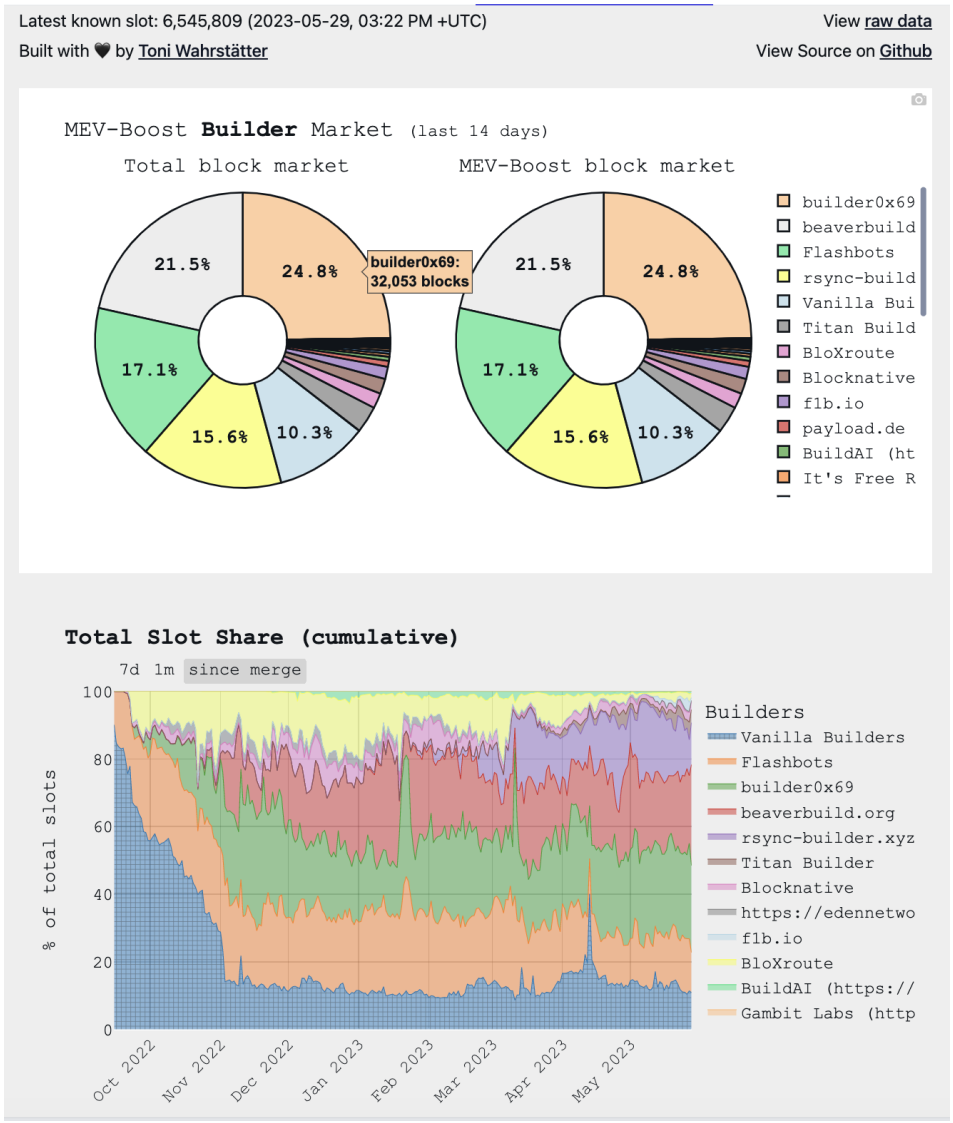


Figure 142: Builders Dashboard - MEV-Boost builder market for the last 14 days and total cumulative slot share (select from time ranges: 7 days, 1 month, since merge). Mevboost.pics.(29 May 2023)

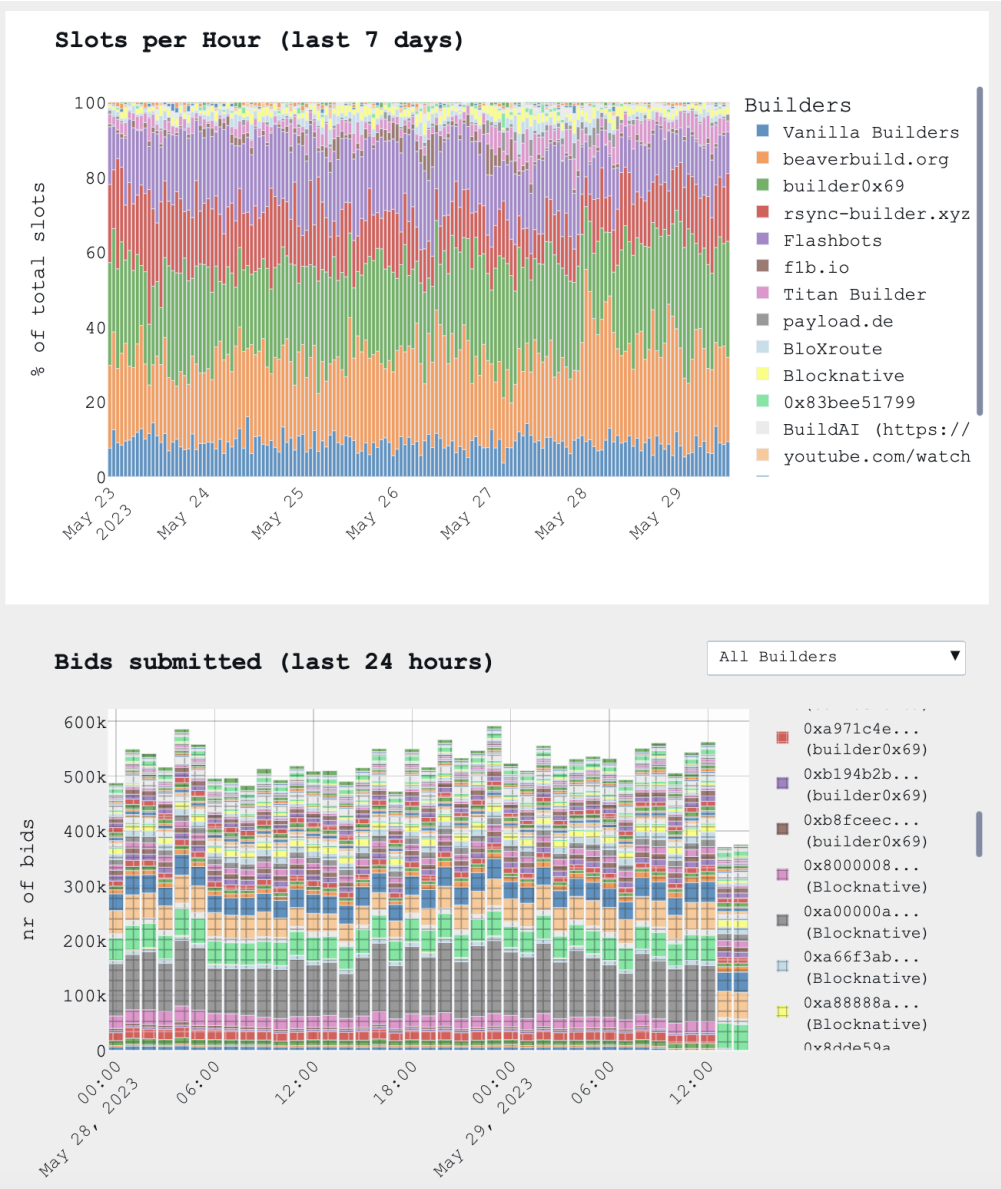


Figure 143: Builders Dashboard - Slots per hour (last 7 days) and bids submitted for the last 24 hours (select all builders, or one from the list provided). Mevboost.pics.(29 May 2023)

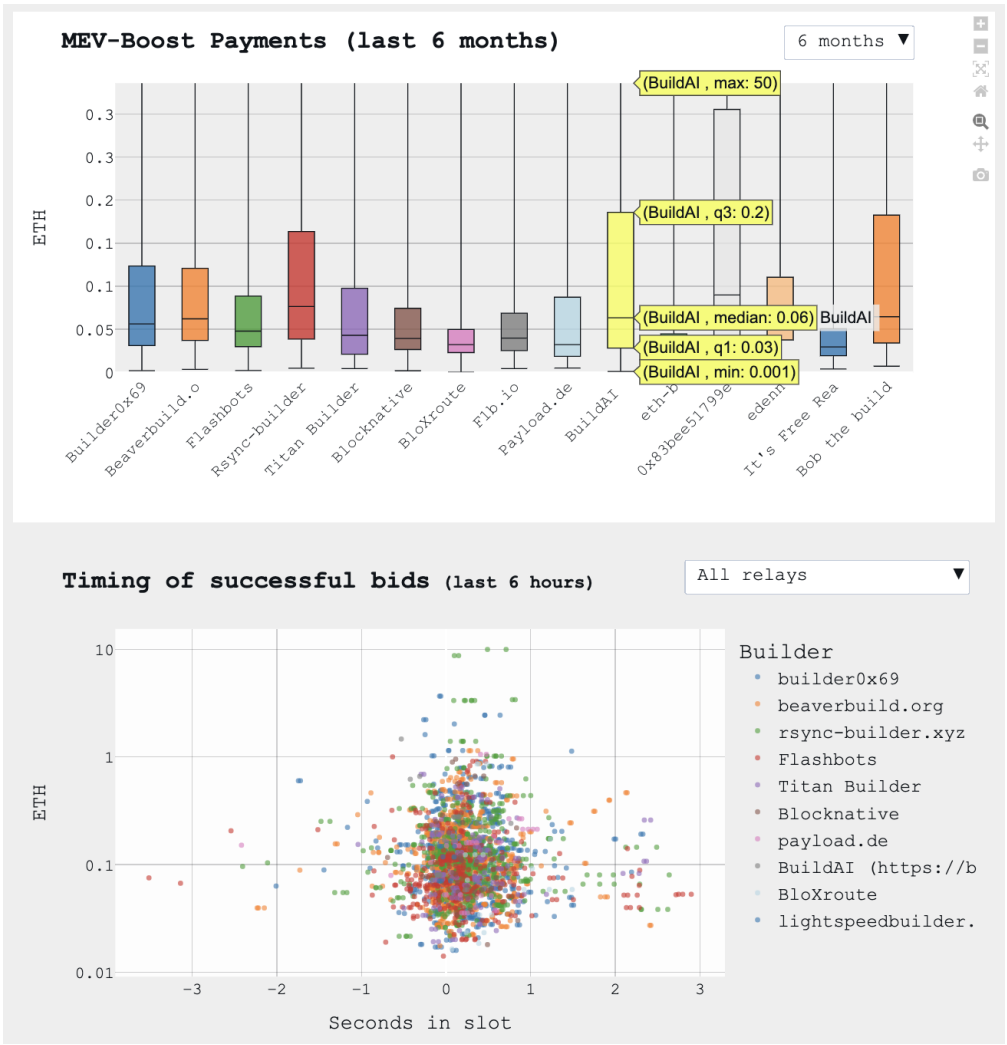
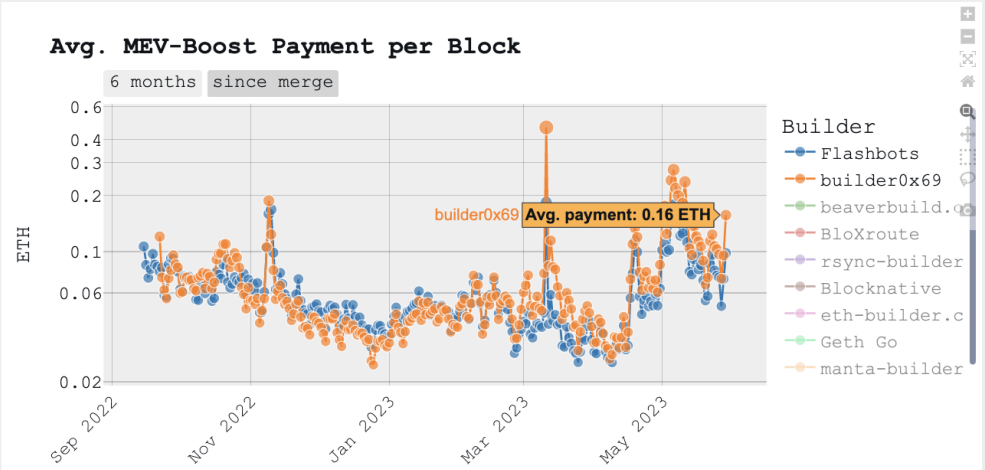


Figure 144: Builders Dashboard - MEV-Boost payments (select from 48 hours, 7 days, 30 days, or 6 months) and timing of the successful bids (select from all relays, or from the list provided). Mevboost.pics.(29 May 2023)



Builders Overview (last 14 days)

Label	Blocks	Builder Public Key
beaverbuild.org	19,532	0x96a59d355b1f65e270b29981dd113625732539e955a1beeecbc471dd0196c4804574ff871d47ed34ff6d921061e9fc
Flashbots	12,514	0x81babeec8c9f2bb9c329fd8a3b176032fe0ab5f3b92a3f44d4575a231c7bd9c31d10b6328ef68ed1e8c02a3dbc8e80
builder0x69	12,329	0x8bc8d110f8b5207e7edc407e8fa033937ddfe8d2c6f18c12a6171400eb6e04d49238ba2b0a95e633d15558e6a706fb
rsync-builder.xyz	8,651	0x945fc51bf63613257792926c9155d7ae32db73155dc13bdfe61cd476f1fd2297b66601e8721b723cef11e4e6682e9d8
rsync-builder.xyz	7,327	0x83d3495a2951065cf19c4d282afca0a635a39f6504bd76282ed0138fe28680ec60fa3fd149e6d27a94a7d90e7b1fb6
builder0x69	6,027	0xb194b2b8ec91a71c18f84838252346792 99d146495a08db3bf3fb955e1d85a5fca77e88de93a74f4e32320fc922d30
beaverbuild.org	5,960	0xb5d883565500910f3f10f0a2e3a031139d972117a3b67da191ff93ba00ba26502d9b65385b5bca5e7c587273e40f23
builder0x69	5,071	0xb8fceec09779ff758918a849bfe8ab43cea79f6a98320af0af5b030f6a7850fcc5883cb965d02efb10eed1ffa987e899
builder0x69	4,782	0xa971c4ee4ac5d47e0fb9e16be05981bfe51458f14c06b7a020304099c23d2d9952d4254cc50f291c385d15e7cae0cf
Flashbots	4,566	0xa1dead01e65f0a0eee7b5170223f20c8f0cbf122eac3324d61afbdb33a8885ff8cab2ef514ac2c7698ae0d6289ef27fc
Flashbots	4,547	0x81beef03aafd3dd33ffd7deb337407142c80fea2690e5b3190cfc01bde5753f28982a7857c96172a75a234cb7bcb994
rsync-builder.xyz	3,957	0x978a35c39c41aadbe35ea29712bccffb117cc6ebcad4d86ea463d712af1dc80131d0c650dc29ba29ef27c881f43bd58
builder0x69	3,844	0xa4fb63c2ceeee73d1f1711fadf1c5357ac98cecb999d053be613f469a48f7416999a4da35dd60a7824478661399e677
Titan Builder	1,837	0xb67eaa5efcfa1d17319c344e1e5167811afbfe7922a2cf01c9a361f465597a5dc3a5472bd98843bac88d2541a78eab08
f1b.io	1,737	0xabc387dff20ff4bda974b7f3041ea857d591681cc032715191965 87a2d6b30c953ea4df11acf637db76f462834a8c80e

Figure 145: Builders Dashboard - Average MEV-Boost payments per block (select time range of last 6 months, or since merge) and builders overview of the last 14 days, ordered by the total number of blocks. Mevboost.pics.(29 May 2023)

Validators Dashboard

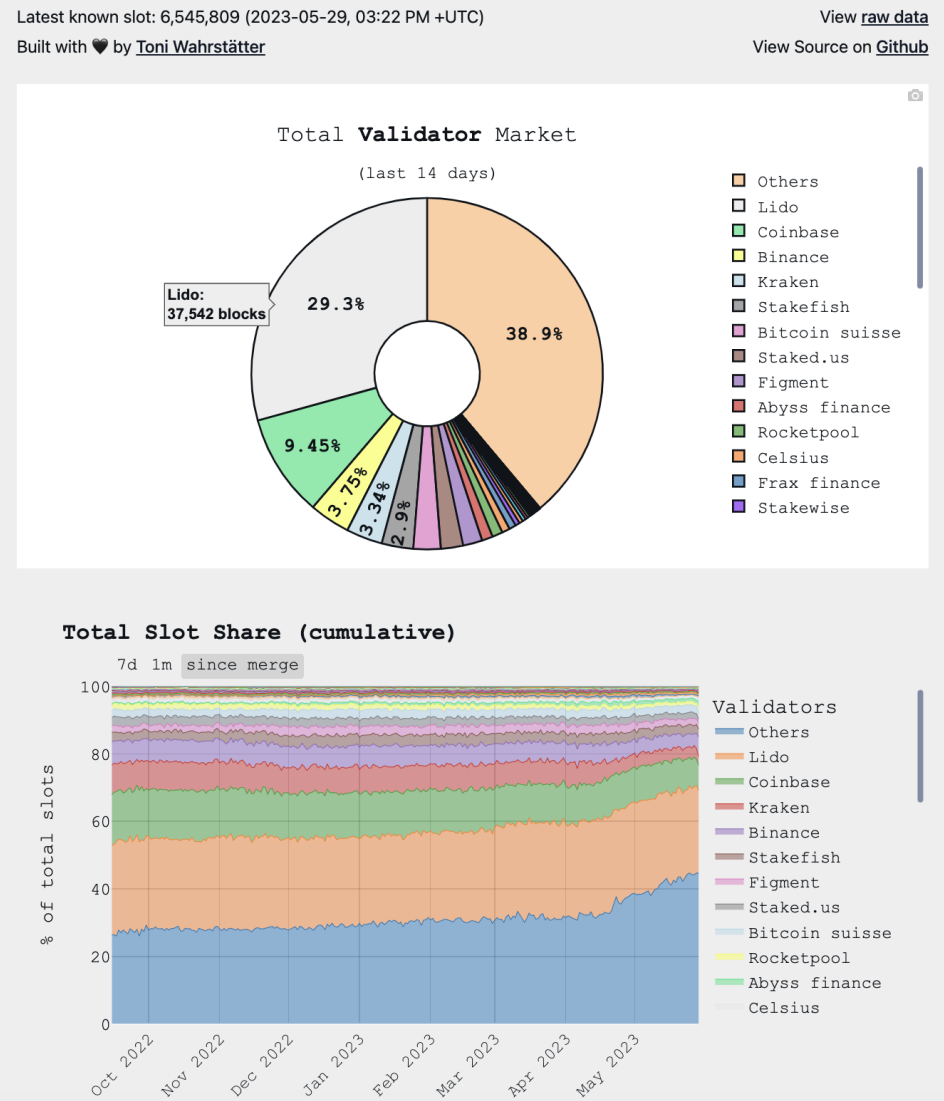


Figure 146: Validators Dashboard - MEV-Boost total validator market for the last 14 days and total cumulative slot share (select from time ranges: 7 days, 1 month, since merge). Mevboost.pics.(29 May 2023)

Figure 147: Validators Dashboard - Slots per hour (last 7 days) and blocks per validator: press play to see the visualisation of the blocks per validator change over time.. Mevboost.pics.(29 May 2023)

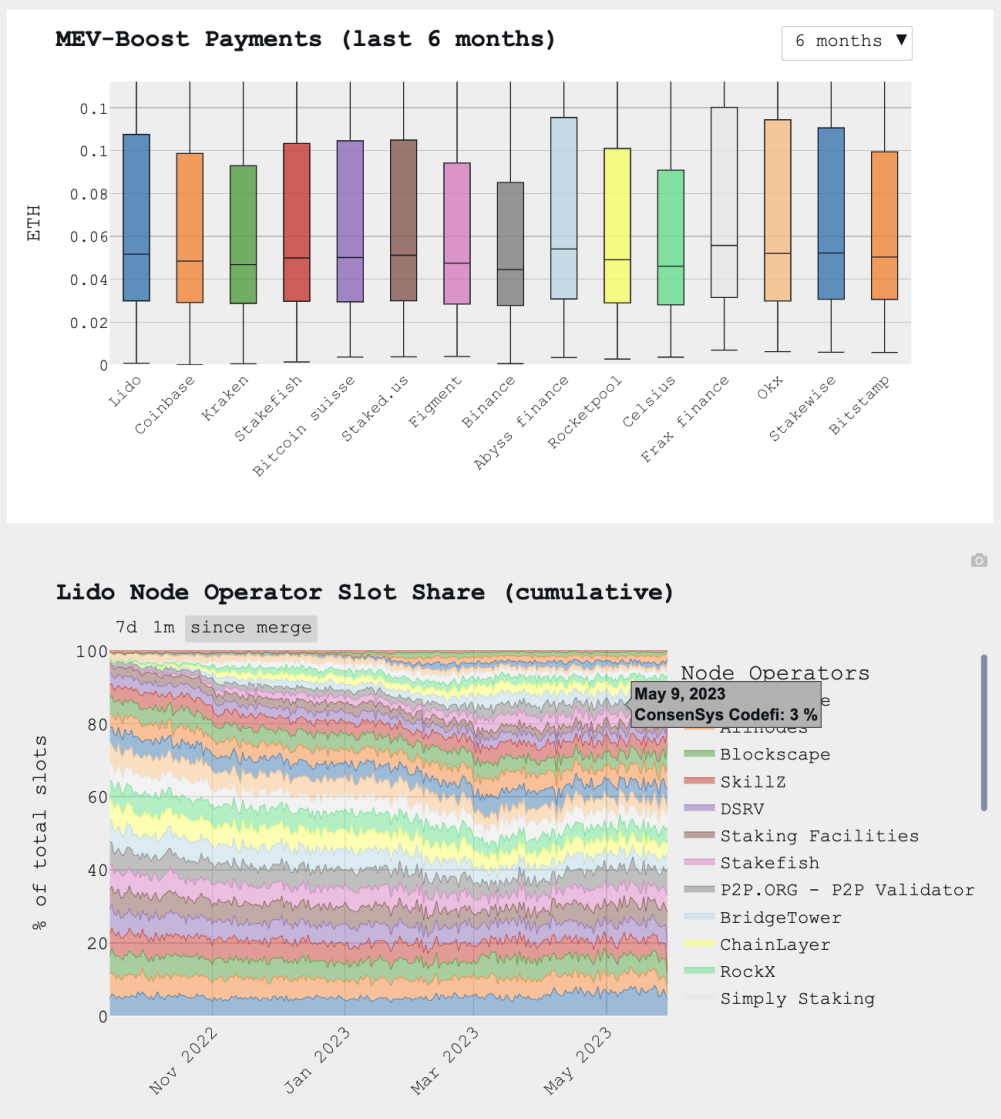
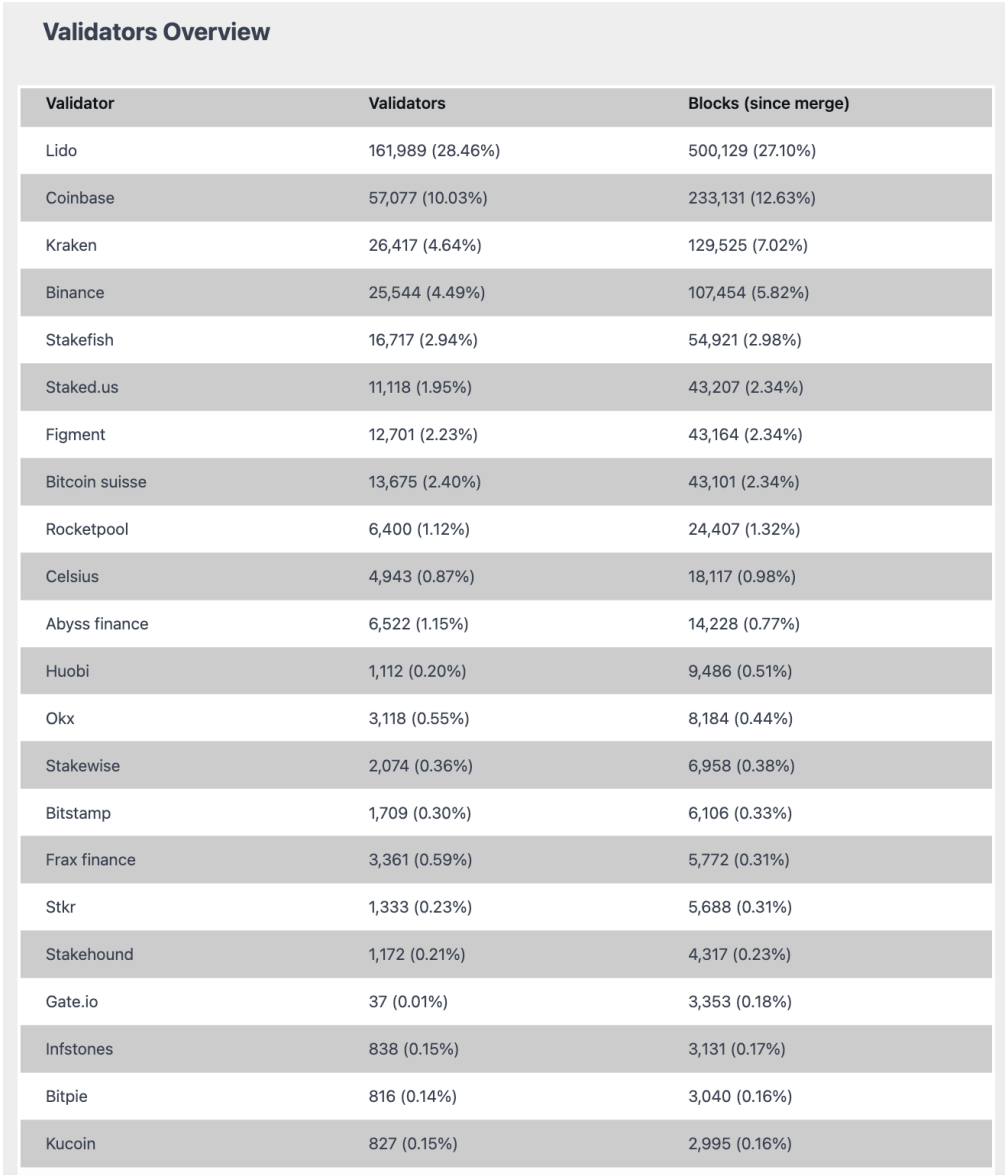


Figure 148: Validators Dashboard - MEV-Boost payments (select from time ranges: 48 hours, 7 days, 30 days or 6 months) and cumulative total of Lido node operator slot share (select time range: 7 days, 1 month or since merge). Mevboost.pics.(29 May 2023)



Validators Overview

Validator	Validators	Blocks (since merge)
Lido	161,989 (28.46%)	500,129 (27.10%)
Coinbase	57,077 (10.03%)	233,131 (12.63%)
Kraken	26,417 (4.64%)	129,525 (7.02%)
Binance	25,544 (4.49%)	107,454 (5.82%)
Stakefish	16,717 (2.94%)	54,921 (2.98%)
Staked.us	11,118 (1.95%)	43,207 (2.34%)
Figment	12,701 (2.23%)	43,164 (2.34%)
Bitcoin suisse	13,675 (2.40%)	43,101 (2.34%)
Rocketpool	6,400 (1.12%)	24,407 (1.32%)
Celsius	4,943 (0.87%)	18,117 (0.98%)
Abyss finance	6,522 (1.15%)	14,228 (0.77%)
Huobi	1,112 (0.20%)	9,486 (0.51%)
Okx	3,118 (0.55%)	8,184 (0.44%)
Stakewise	2,074 (0.36%)	6,958 (0.38%)
Bitstamp	1,709 (0.30%)	6,106 (0.33%)
Frax finance	3,361 (0.59%)	5,772 (0.31%)
Stkr	1,333 (0.23%)	5,688 (0.31%)
Stakehound	1,172 (0.21%)	4,317 (0.23%)
Gate.io	37 (0.01%)	3,353 (0.18%)
Infstones	838 (0.15%)	3,131 (0.17%)
Bitpie	816 (0.14%)	3,040 (0.16%)
Kucoin	827 (0.15%)	2,995 (0.16%)

Figure 149: Validators Dashboard - Validators overview with Staker/Validator, number of validators and number of blocks proposed by the staking entity since the merge. Mevboost.pics.(29 May 2023)

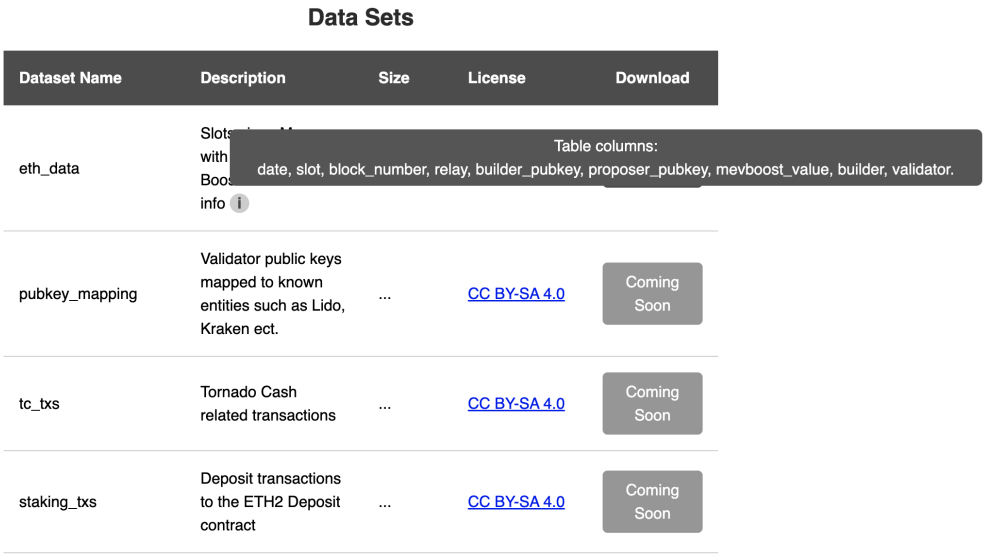


Figure 150: Raw data can be downloaded from Mevboost.pics. Currently only the first dataset is available for download. (29 May 2023). The public key mapping dataset is now also available and will be updated daily (30 May 2023)

Metrika

Withdrawals

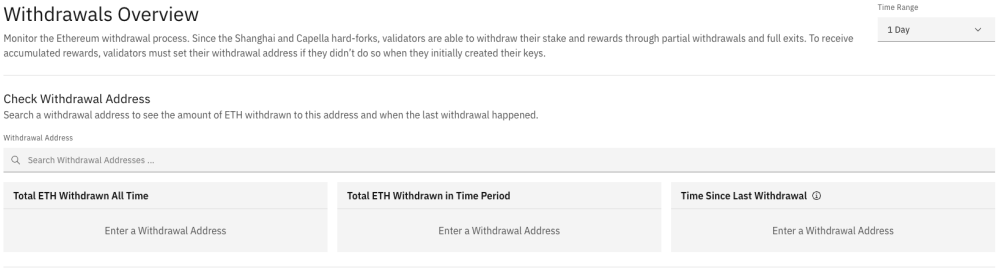


Figure 151: Details will be displayed when a withdrawal address is entered. Metrika. (21 June 2023).

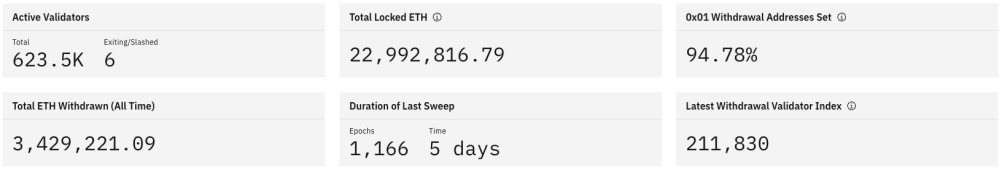


Figure 152: Network level statistics. Metrika. (21 June 2023).

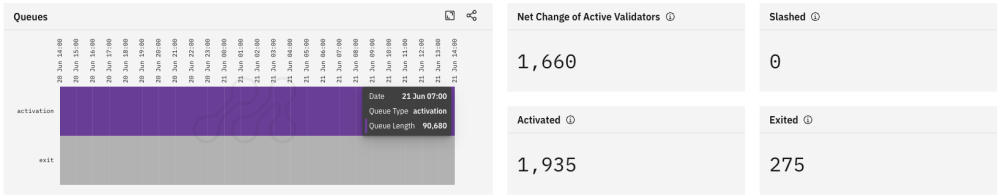


Figure 153: Activation queue. Metrika. (21 June 2023).

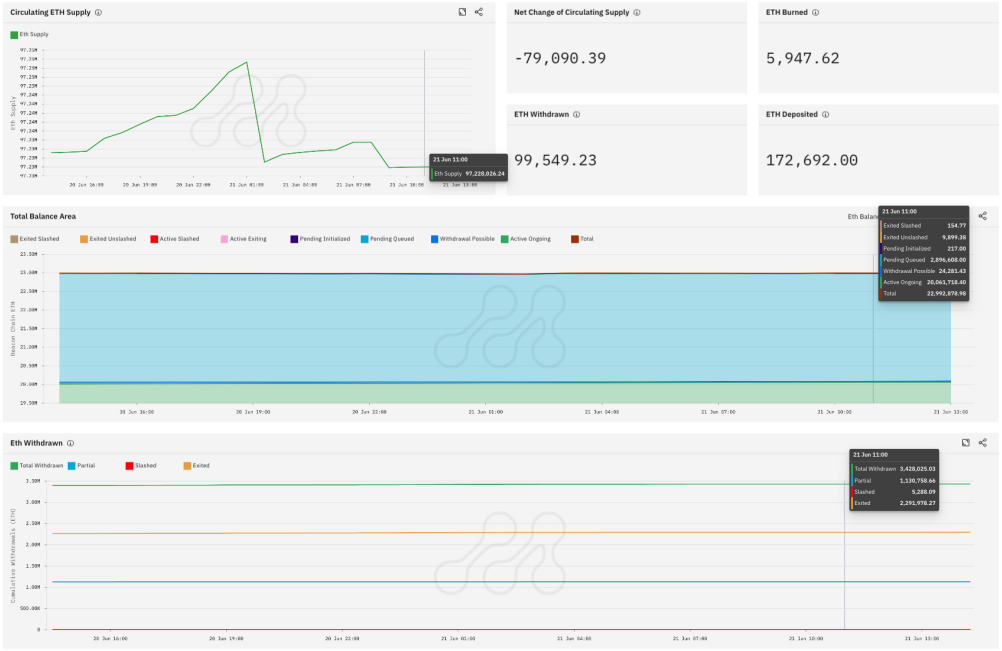


Figure 154: Circulating ETH supply (amount of ETH on the Execution Layer), net change of supply (ETH withdrawn - ETH burned - ETH deposited). Metrika. (21 June 2023).

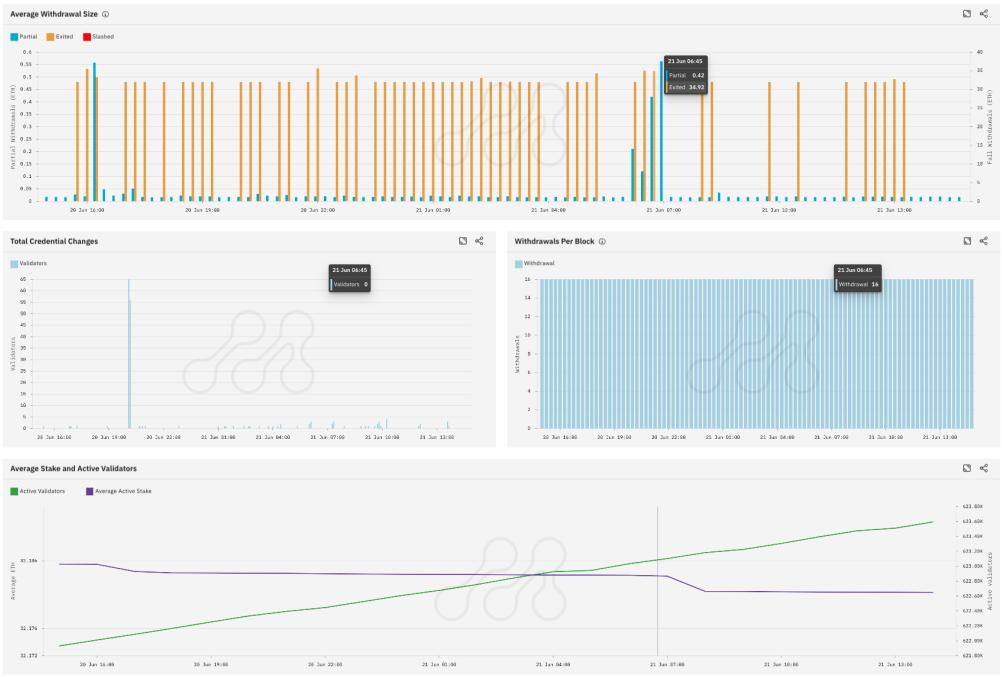


Figure 155: Average withdrawal split by withdrawal type: partial, exited or slashed, credential changes, no. of withdrawals per block. Metrika. (21 June 2023).

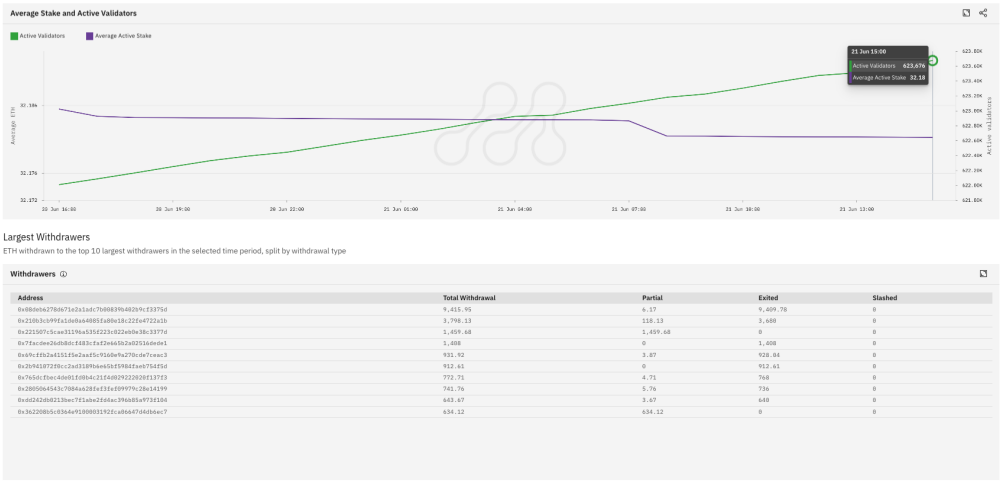


Figure 156: Average stake and active validators, and largest total withdrawals for a withdrawal address, split by withdrawal type. Metrika. (21 June 2023).

Nansen

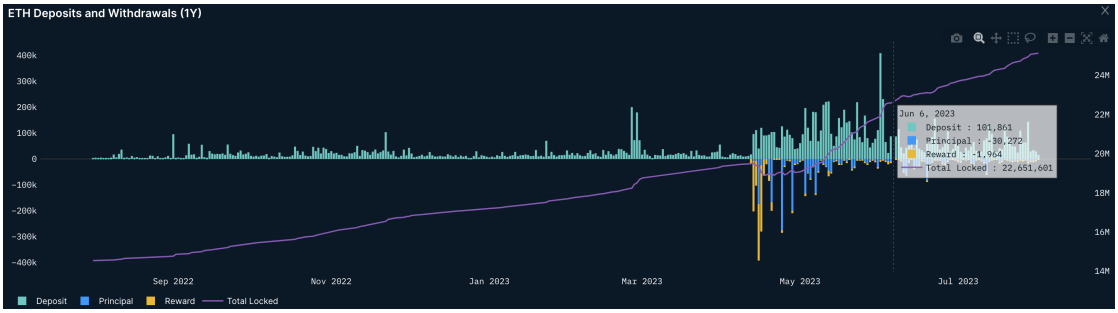


Figure 157: *Deposits*: ETH that has been sent to the beacon deposit contract.
Principal: Principal amount of ETH deposited that have been withdrawn to a wallet.
Reward: Earned rewards that have been withdrawn to a wallet.
Cumulative Sum: Deposits minus amount withdrawn.
ETH Locked: All ETH that "is out of circulation", i.e. ETH staked on Beacon chain, ETH deposited to the beacon contract but not validating yet, and rewards on the Beacon chain. Nansen Shapella dashboard (2 August 2023)

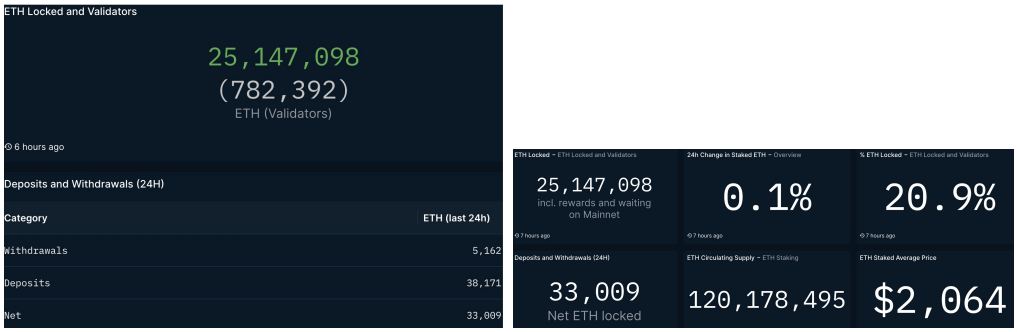
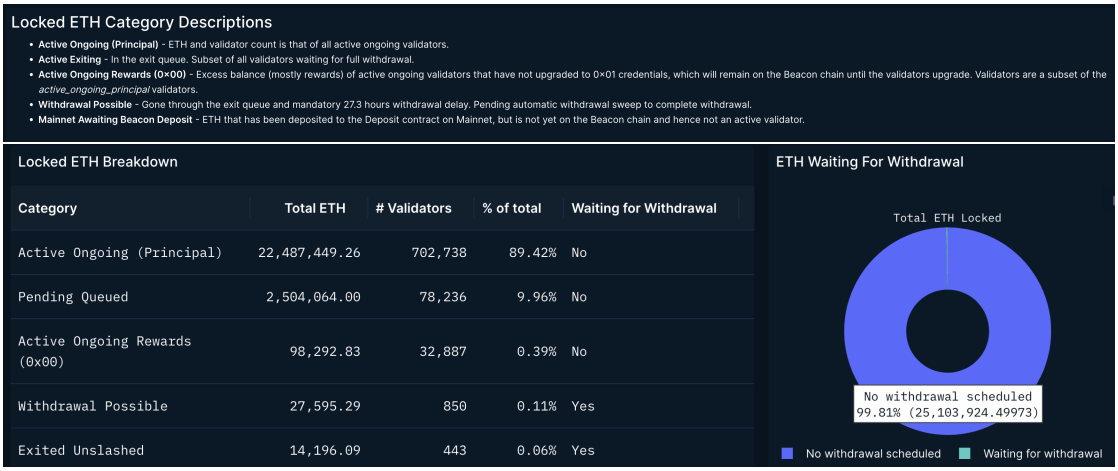
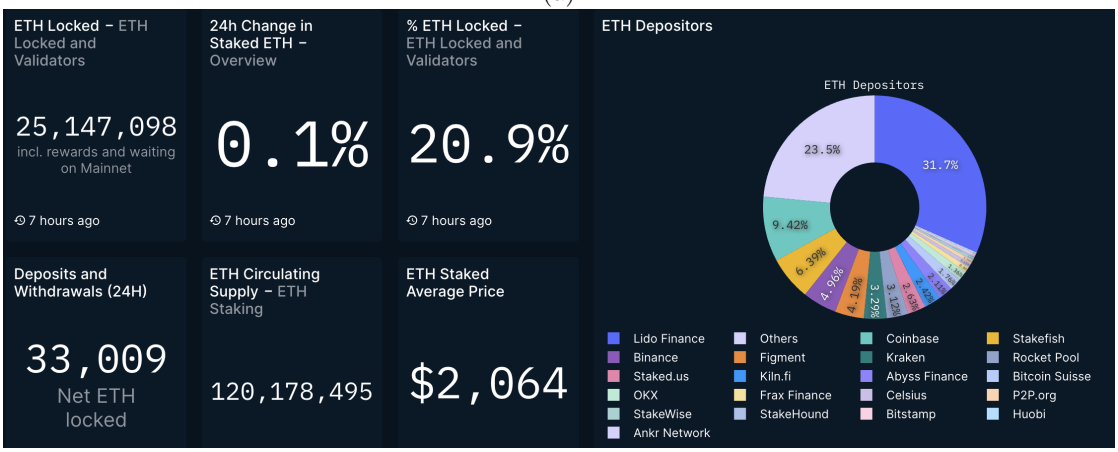


Figure 158: Locked ETH and validators. Nansen Shapella dashboard (2 August 2023)



(a)



(b)

Figure 159: (a) Locked ETH breakdown, (b) ETH depositors. Nansen Shapella dashboard (2 August 2023)

Top ETH Depositing Addresses

Calculated using Amount of ETH Deposited and Staked Duration

Address	ETH Staked	Average Price	Tx Count	First Deposit Date	Scoring
Lido Finance: stETH Token	6,274,784	$2,492	722	Dec 20 2020	2.09
Lido Finance: Staking Router	1,741,920	$1,850	74	May 18 2023	-0.11
Stakefish: Batch Deposit	1,333,888	$1,764	299	Jan 28 2022	0.01
Figment: ETH2 Deposit 1	1,118,848	$1,917	210	Feb 22 2022	0.06
Kraken: ETH2 Staking 0xd4	1,107,200	$1,868	803	Dec 03 2020	0.58
Staked.us: ETH2 Staking 0x39	735,072	$1,570	511	Nov 09 2020	0.31
Binance: ETH2 Staking 0xbdd	709,440	$1,961	39	Oct 15 2021	0.07
Abyss Finance: Eth2 Staking 0xfa	543,744	$1,908	629	Feb 16 2021	0.03
BatchDeposit	368,320	$1,866	54	Nov 11 2022	-0.02
OKX: ETH2 Staking 0x5a0	351,521	$1,841	619	Dec 16 2020	0.02

Figure 160: Top ETH depositing addresses. Nansen Shapella dashboard (2 August 2023)

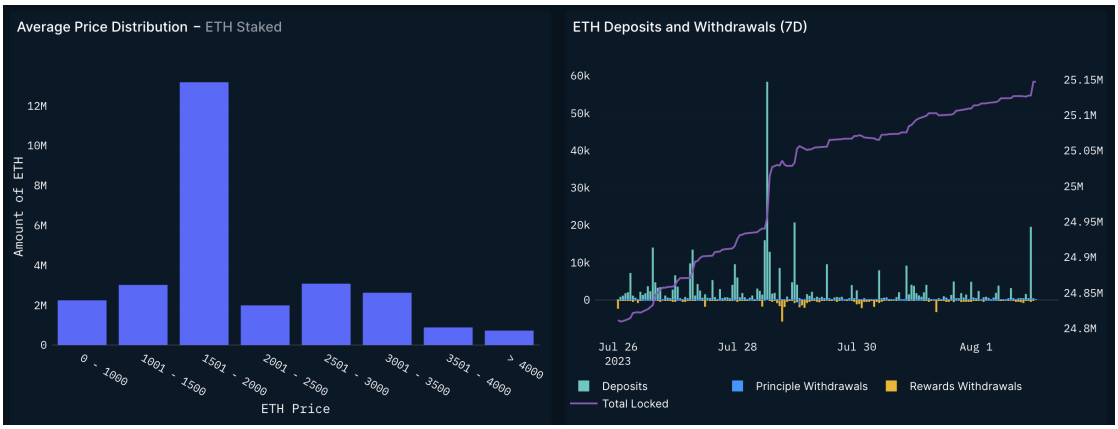


Figure 161: Distribution of average price and of staked ETH. Nansen Shapella dashboard (2 August 2023)

Figure 162: ETH and validators waiting for full exit. Nansen Eth2 dashboard (2 August 2023)

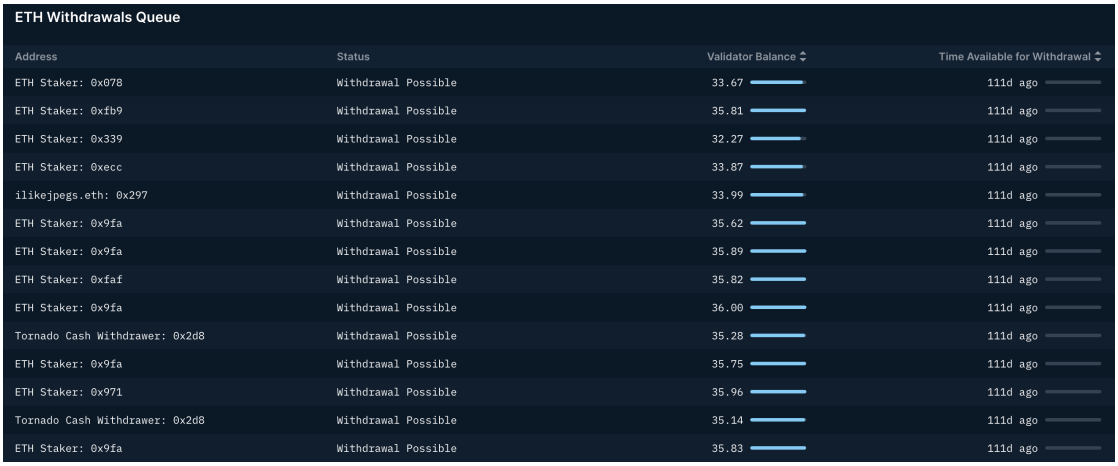
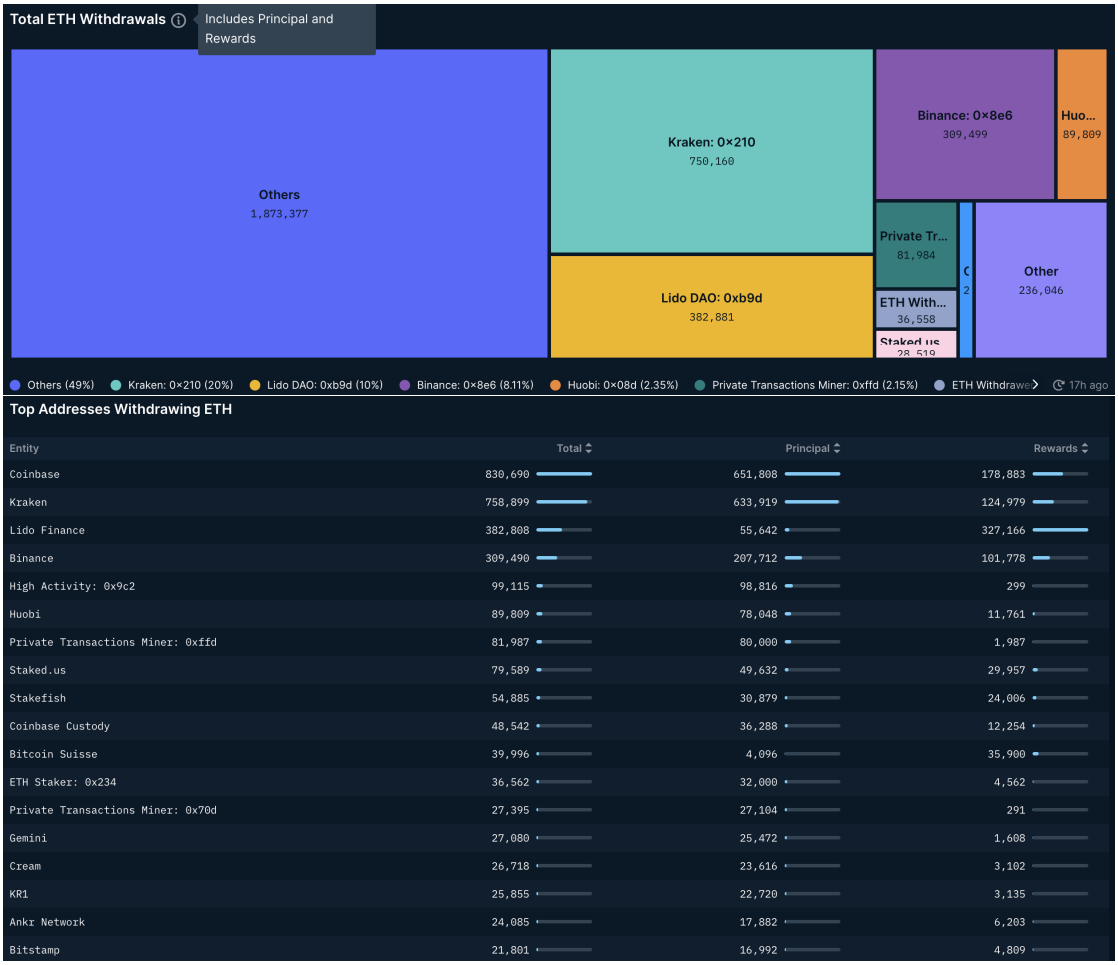


Figure 163: Withdrawal queue. Nansen Eth2 dashboard (2 August 2023)



Top Addresses Withdrawing ETH

Entity	Total	Principal	Rewards
Coinbase	830,690	651,808	178,883
Kraken	758,899	633,919	124,979
Lido Finance	382,808	55,642	327,166
Binance	309,490	207,712	101,778
High Activity: 0x9c2	99,115	98,816	299
Huobi	89,809	78,048	11,761
Private Transactions Miner: 0xffd	81,987	80,000	1,987
Staked.us	79,589	49,632	29,957
Stakefish	54,885	30,879	24,006
Coinbase Custody	48,542	36,288	12,254
Bitcoin Suisse	39,996	4,096	35,900
ETH Staker: 0x234	36,562	32,000	4,562
Private Transactions Miner: 0x70d	27,395	27,104	291
Gemini	27,080	25,472	1,608
Cream	26,718	23,616	3,102
KR1	25,855	22,720	3,135
Ankr Network	24,085	17,882	6,203
Bitstamp	21,801	16,992	4,809

Figure 164: Withdrawal metrics. Nansen Eth2 dashboard (2 August 2023)

BeaconScan

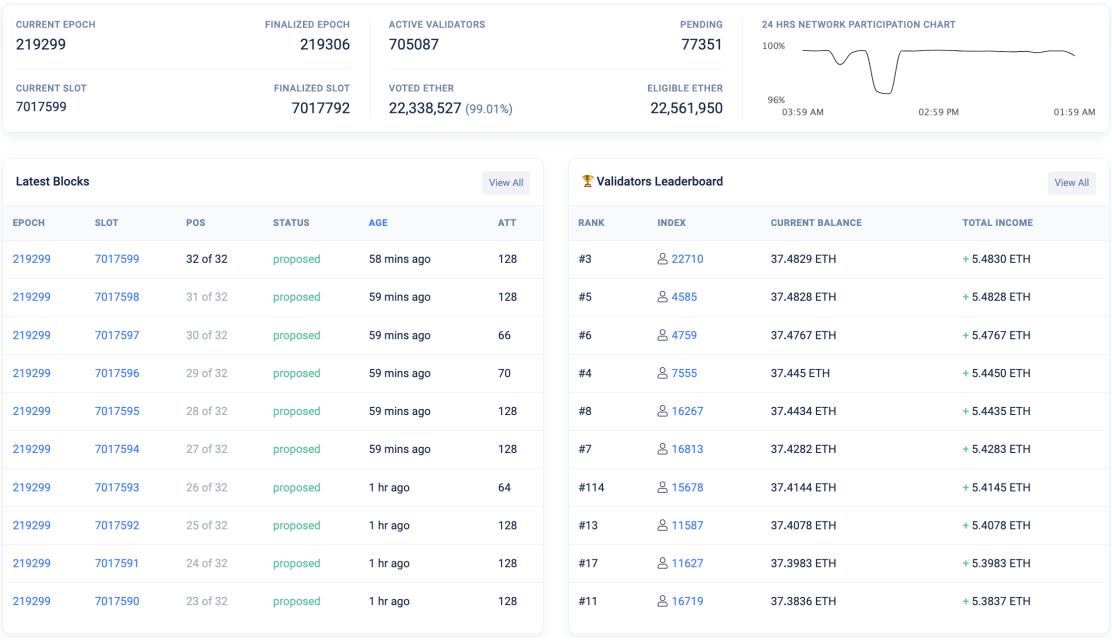
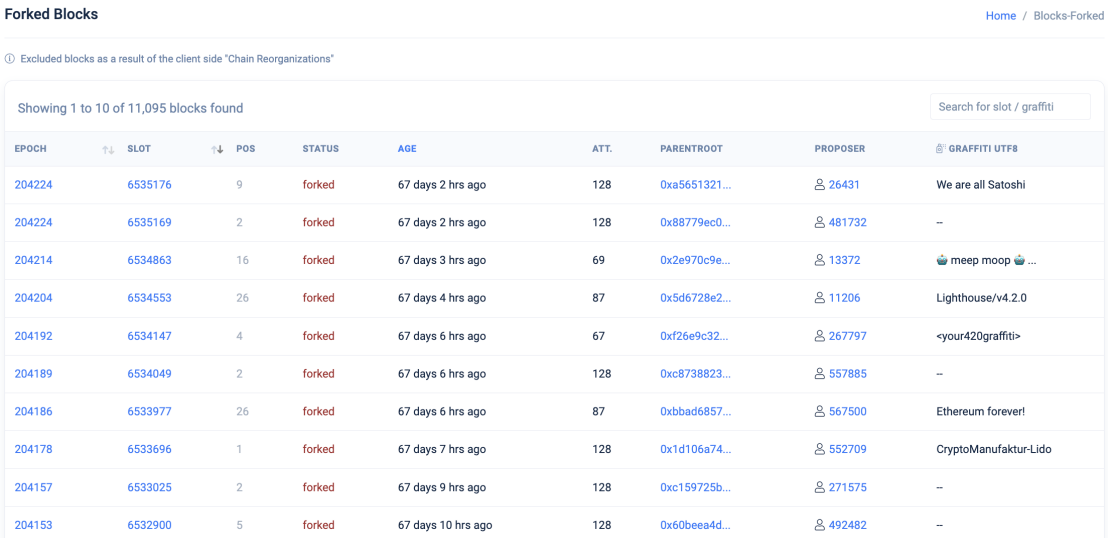


Figure 165: View of current slot, epoch, number of active & pending validators, voted & eligible ETH, small chart of network participation, latest beacon chain blocks and the validators leader board. BeaconScan (3 August 2023)



Forked Blocks

Home / Blocks-Forked

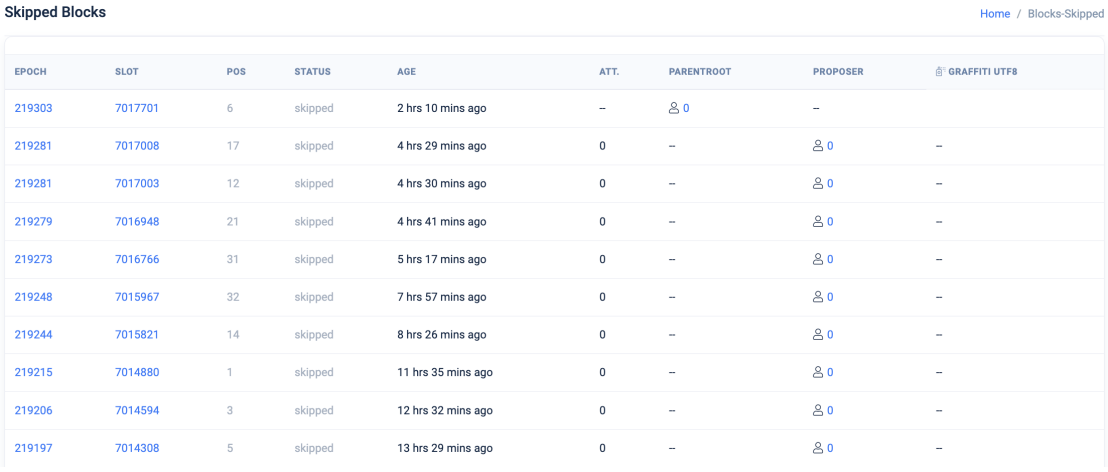
ⓘ Excluded blocks as a result of the client side "Chain Reorganizations"

Showing 1 to 10 of 11,095 blocks found

Search for slot / graffiti

EPOCH	SLOT	POS	STATUS	AGE	ATT.	PARENTROOT	PROPOSER	GRAFFITI UTF8
204224	6535176	9	forked	67 days 2 hrs ago	128	0xa5651321...	26431	We are all Satoshi
204224	6535169	2	forked	67 days 2 hrs ago	128	0x88779ec0...	481732	--
204214	6534863	16	forked	67 days 3 hrs ago	69	0x2e970c9e...	13372	meep moop ...
204204	6534553	26	forked	67 days 4 hrs ago	87	0x5d6728e2...	11206	Lighthouse/v4.2.0
204192	6534147	4	forked	67 days 6 hrs ago	67	0xf26e9c32...	267797	<your420graffiti>
204189	6534049	2	forked	67 days 6 hrs ago	128	0xc8738823...	557885	--
204186	6533977	26	forked	67 days 6 hrs ago	87	0xbbad6857...	567500	Ethereum forever!
204178	6533696	1	forked	67 days 7 hrs ago	128	0x1d106a74...	552709	CryptoManufaktur-Lido
204157	6533025	2	forked	67 days 9 hrs ago	128	0xc159725b...	271575	--
204153	6532900	5	forked	67 days 10 hrs ago	128	0x60beea4d...	492482	--

Figure 166: Forked blocks. BeaconScan (3 August 2023)

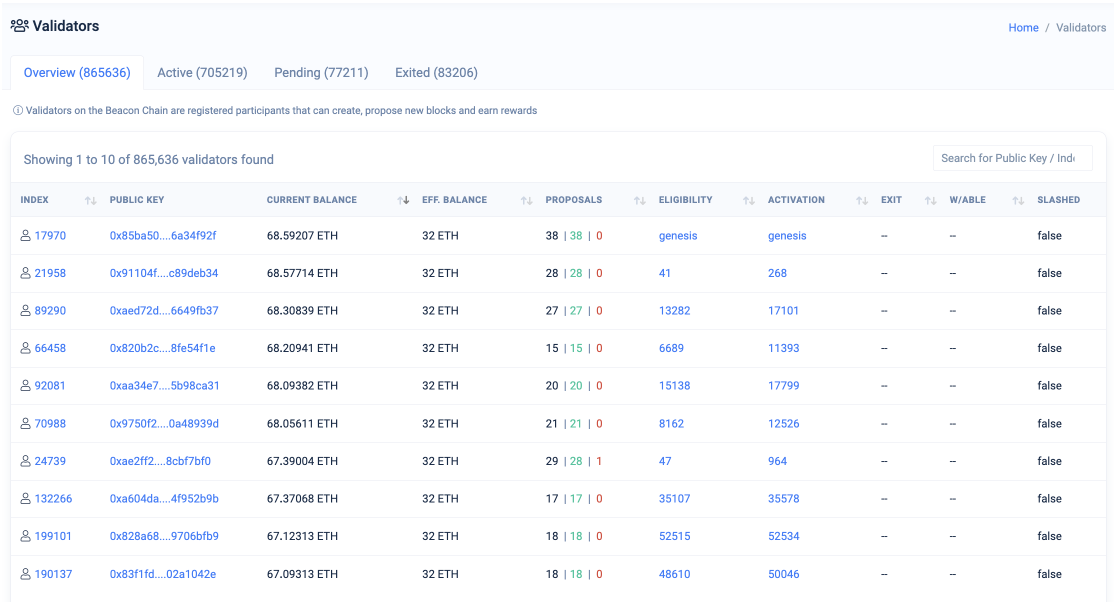


Skipped Blocks

Home / Blocks-Skipped

EPOCH	SLOT	POS	STATUS	AGE	ATT.	PARENTROOT	PROPOSER	GRAFFITI UTF8
219303	7017701	6	skipped	2 hrs 10 mins ago	--	0	--	
219281	7017008	17	skipped	4 hrs 29 mins ago	0	--	0	--
219281	7017003	12	skipped	4 hrs 30 mins ago	0	--	0	--
219279	7016948	21	skipped	4 hrs 41 mins ago	0	--	0	--
219273	7016766	31	skipped	5 hrs 17 mins ago	0	--	0	--
219248	7015967	32	skipped	7 hrs 57 mins ago	0	--	0	--
219244	7015821	14	skipped	8 hrs 26 mins ago	0	--	0	--
219215	7014880	1	skipped	11 hrs 35 mins ago	0	--	0	--
219206	7014594	3	skipped	12 hrs 32 mins ago	0	--	0	--
219197	7014308	5	skipped	13 hrs 29 mins ago	0	--	0	--

Figure 167: Skipped blocks. BeaconScan (3 August 2023)



Validators

Home / Validators

Overview (865636) | Active (705219) | Pending (77211) | Exited (83206)

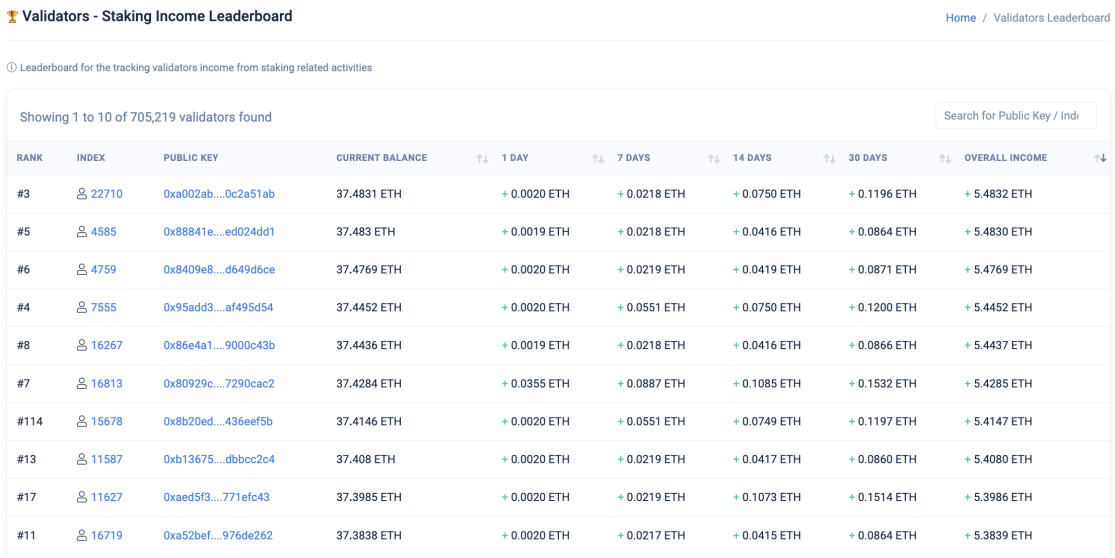
ⓘ Validators on the Beacon Chain are registered participants that can create, propose new blocks and earn rewards

Showing 1 to 10 of 865,636 validators found

Search for Public Key / Ind

INDEX	PUBLIC KEY	CURRENT BALANCE	EFF. BALANCE	PROPOSALS	ELIGIBILITY	ACTIVATION	EXIT	W/ABLE	SLASHED
17970	0x85ba50....6a34f92f	68.59207 ETH	32 ETH	38 | 38 | 0	genesis	genesis	--	--	false
21958	0x91104f....c89deb34	68.57714 ETH	32 ETH	28 | 28 | 0	41	268	--	--	false
89290	0xaed72d....6649fb37	68.30839 ETH	32 ETH	27 | 27 | 0	13282	17101	--	--	false
66458	0x820b2c....8fe54f1e	68.20941 ETH	32 ETH	15 | 15 | 0	6689	11393	--	--	false
92081	0xaa34e7....5b98ca31	68.09382 ETH	32 ETH	20 | 20 | 0	15138	17799	--	--	false
70988	0x9750f2....0a48939d	68.05611 ETH	32 ETH	21 | 21 | 0	8162	12526	--	--	false
24739	0xae2ff2....8cbf7bf0	67.39004 ETH	32 ETH	29 | 28 | 1	47	964	--	--	false
132266	0xa604da....4f952b9b	67.37068 ETH	32 ETH	17 | 17 | 0	35107	35578	--	--	false
199101	0x828a68....9706bfb9	67.12313 ETH	32 ETH	18 | 18 | 0	52515	52534	--	--	false
190137	0x83f1fd....02a1042e	67.09313 ETH	32 ETH	18 | 18 | 0	48610	50046	--	--	false

Figure 168: List of validators. BeaconScan (3 August 2023)



Validators - Staking Income Leaderboard

Home / Validators Leaderboard

ⓘ Leaderboard for the tracking validators income from staking related activities

Showing 1 to 10 of 705,219 validators found

Search for Public Key / Ind

RANK	INDEX	PUBLIC KEY	CURRENT BALANCE	1 DAY	7 DAYS	14 DAYS	30 DAYS	OVERALL INCOME
#3	22710	0xa002ab....0c2a51ab	37.4831 ETH	+ 0.0020 ETH	+ 0.0218 ETH	+ 0.0750 ETH	+ 0.1196 ETH	+ 5.4832 ETH
#5	4585	0x88841e....ed024dd1	37.483 ETH	+ 0.0019 ETH	+ 0.0218 ETH	+ 0.0416 ETH	+ 0.0864 ETH	+ 5.4830 ETH
#6	4759	0x8409e8....d649d6ce	37.4769 ETH	+ 0.0020 ETH	+ 0.0219 ETH	+ 0.0419 ETH	+ 0.0871 ETH	+ 5.4769 ETH
#4	7555	0x95add3....af495d54	37.4452 ETH	+ 0.0020 ETH	+ 0.0551 ETH	+ 0.0750 ETH	+ 0.1200 ETH	+ 5.4452 ETH
#8	16267	0x86e4a1....9000c43b	37.4436 ETH	+ 0.0019 ETH	+ 0.0218 ETH	+ 0.0416 ETH	+ 0.0866 ETH	+ 5.4437 ETH
#7	16813	0x80929c....7290cac2	37.4284 ETH	+ 0.0355 ETH	+ 0.0887 ETH	+ 0.1085 ETH	+ 0.1532 ETH	+ 5.4285 ETH
#114	15678	0x8b20ed....436eef5b	37.4146 ETH	+ 0.0020 ETH	+ 0.0551 ETH	+ 0.0749 ETH	+ 0.1197 ETH	+ 5.4147 ETH
#13	11587	0xb13675....dbbcc2c4	37.408 ETH	+ 0.0020 ETH	+ 0.0219 ETH	+ 0.0417 ETH	+ 0.0860 ETH	+ 5.4080 ETH
#17	11627	0xaed5f3....771efc43	37.3985 ETH	+ 0.0020 ETH	+ 0.0219 ETH	+ 0.1073 ETH	+ 0.1514 ETH	+ 5.3986 ETH
#11	16719	0xa52bef....976de262	37.3838 ETH	+ 0.0020 ETH	+ 0.0217 ETH	+ 0.0415 ETH	+ 0.0864 ETH	+ 5.3839 ETH

Figure 169: Leaderboard of validator staking income. BeaconScan (3 August 2023)

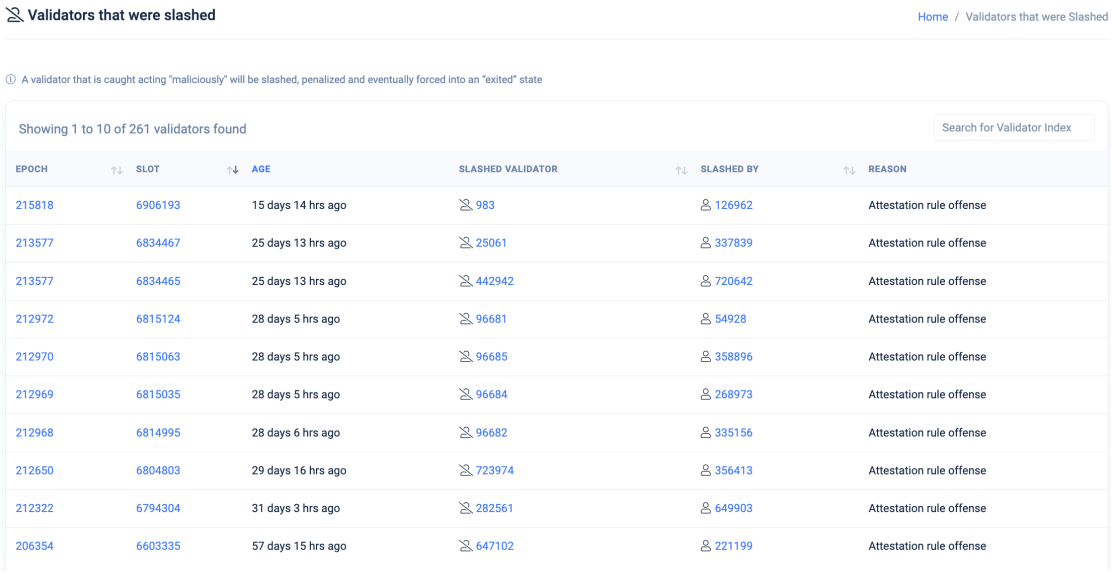


Figure 170: Details of slashed validators. BeaconScan (3 August 2023)

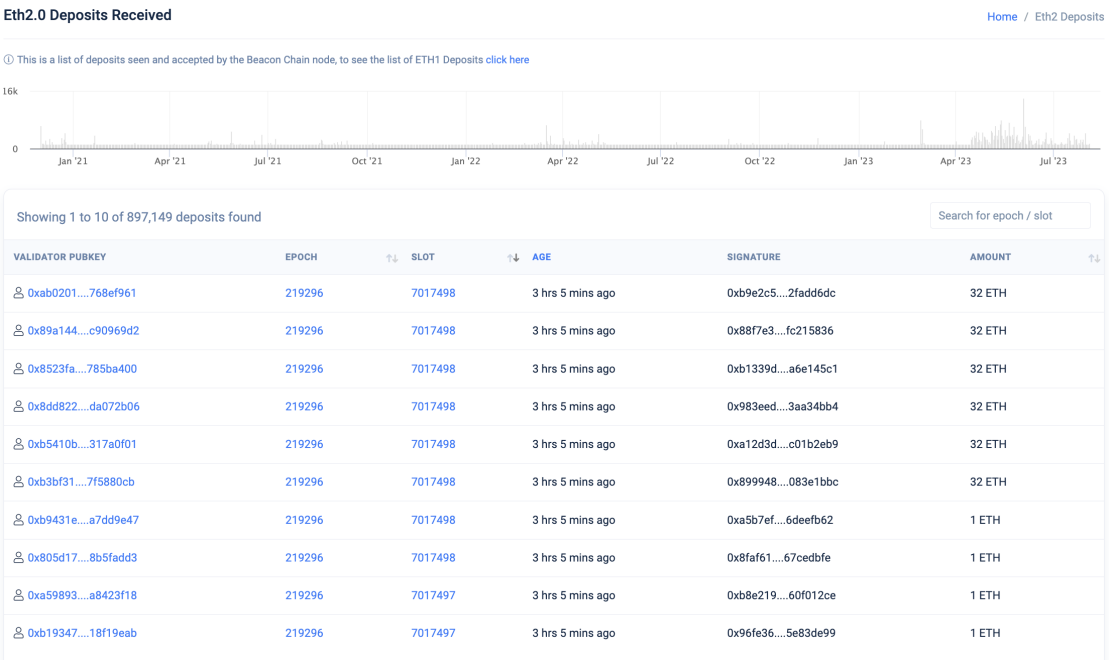


Figure 171: Eth2 Deposits received. BeaconScan (3 August 2023)

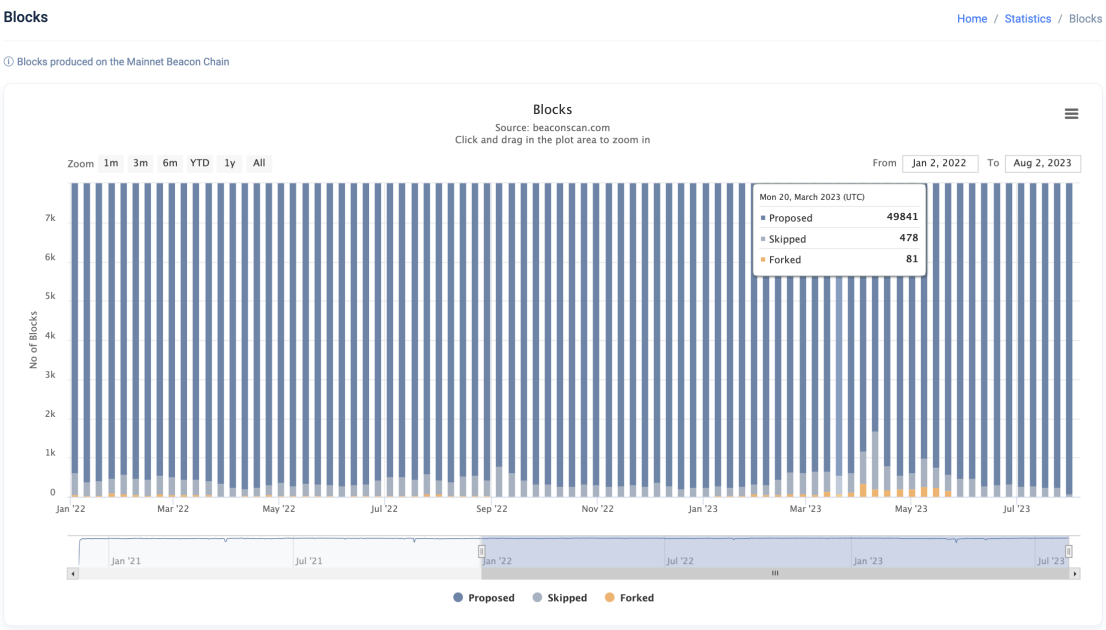


Figure 172: Histogram of proposed, skipped and forked blocks. BeaconScan (3 August 2023)

Figure 173: Graph of number of validators over time. BeaconScan (3 August 2023)

Figure 174: Graph of number of attestations over time. BeaconScan (3 August 2023)

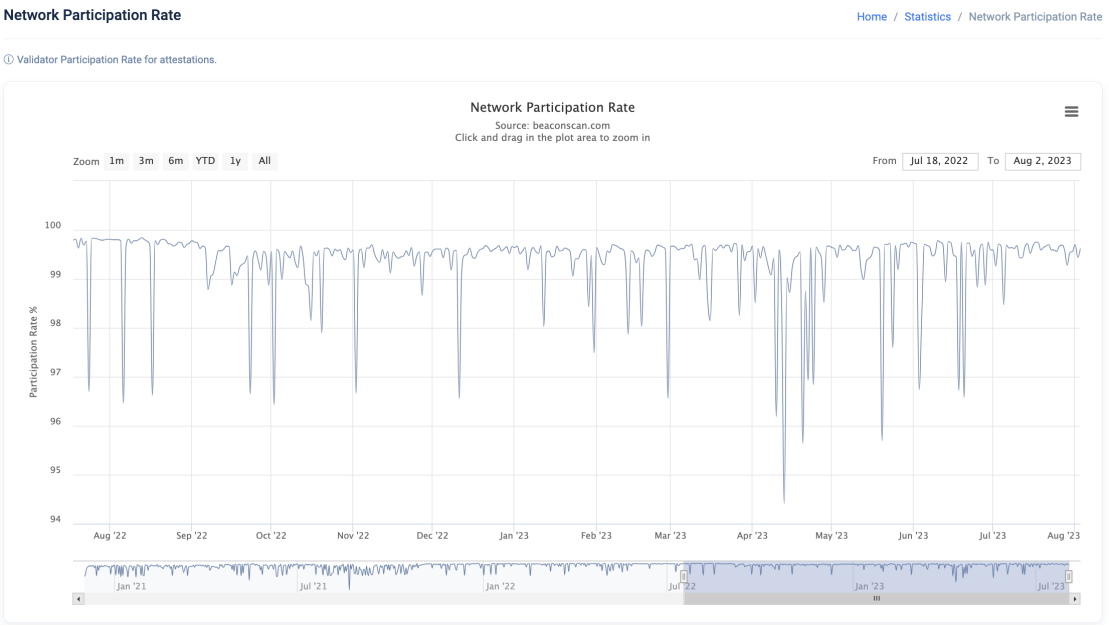


Figure 175: Visualisation of network participant rate. BeaconScan (3 August 2023)

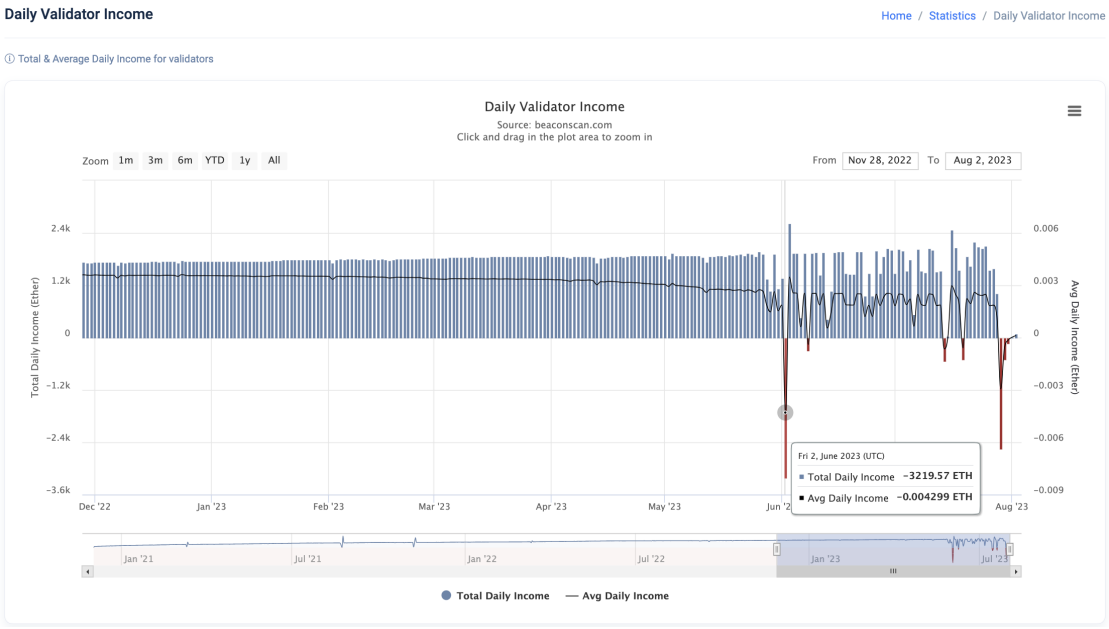


Figure 176: Daily validator income. BeaconScan (3 August 2023)

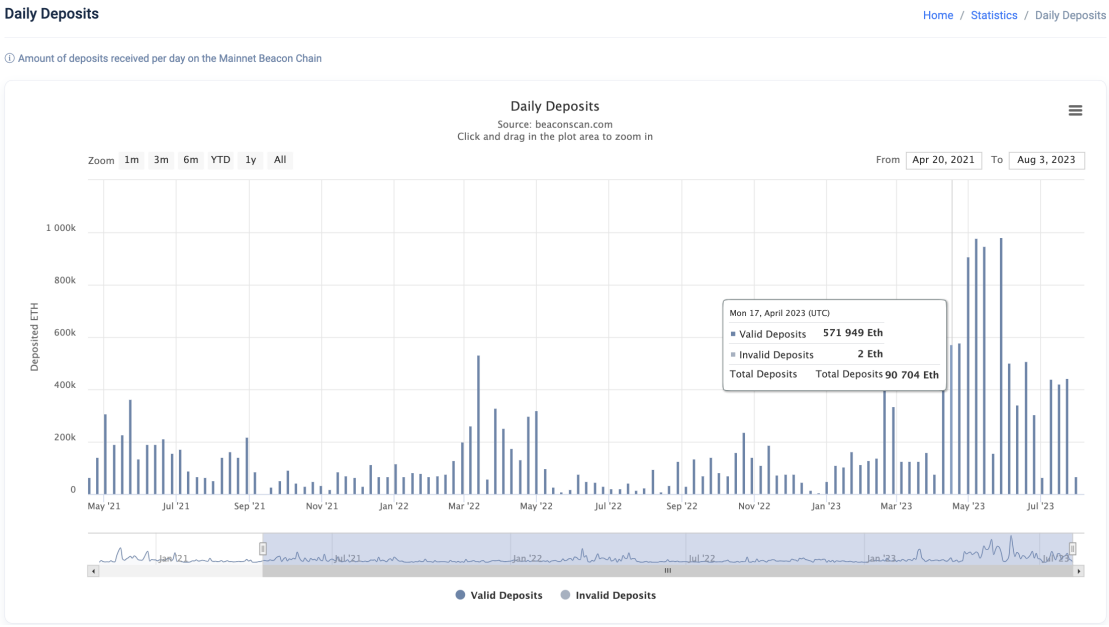


Figure 177: Histogram of daily deposits. BeaconScan (3 August 2023)

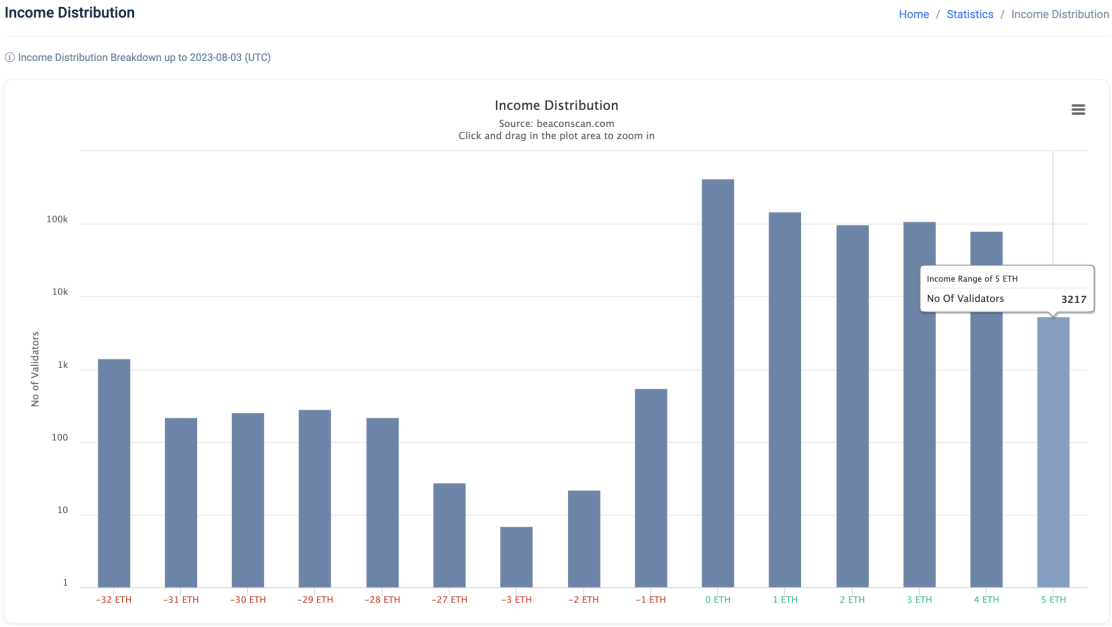


Figure 178: Histogram of income distribution. BeaconScan (3 August 2023)

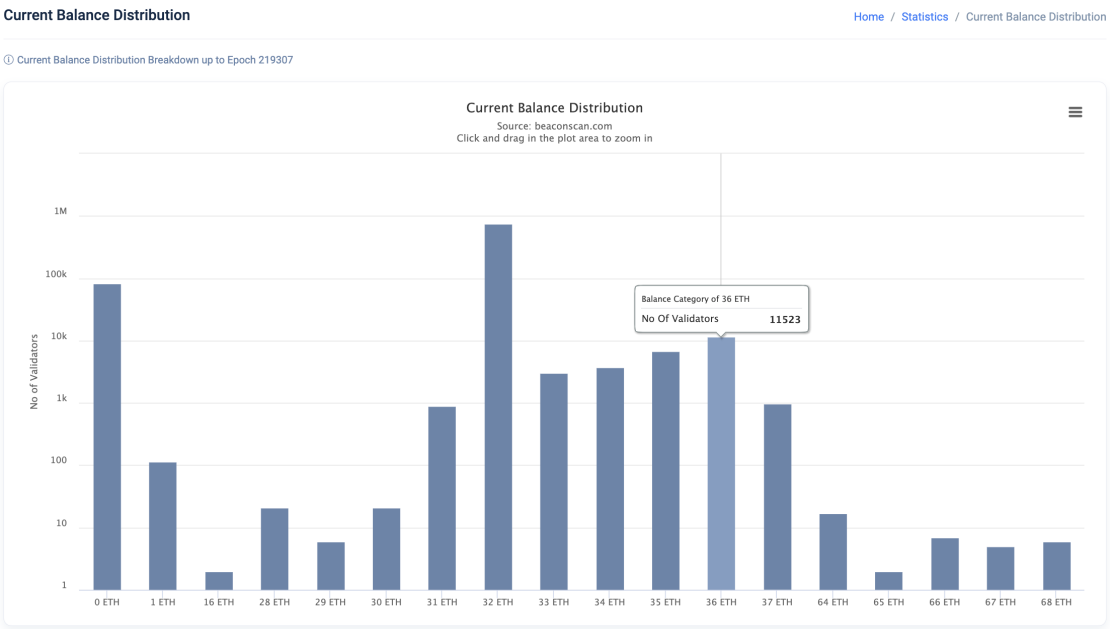


Figure 179: Histogram of current balance distribution. BeaconScan (3 August 2023)

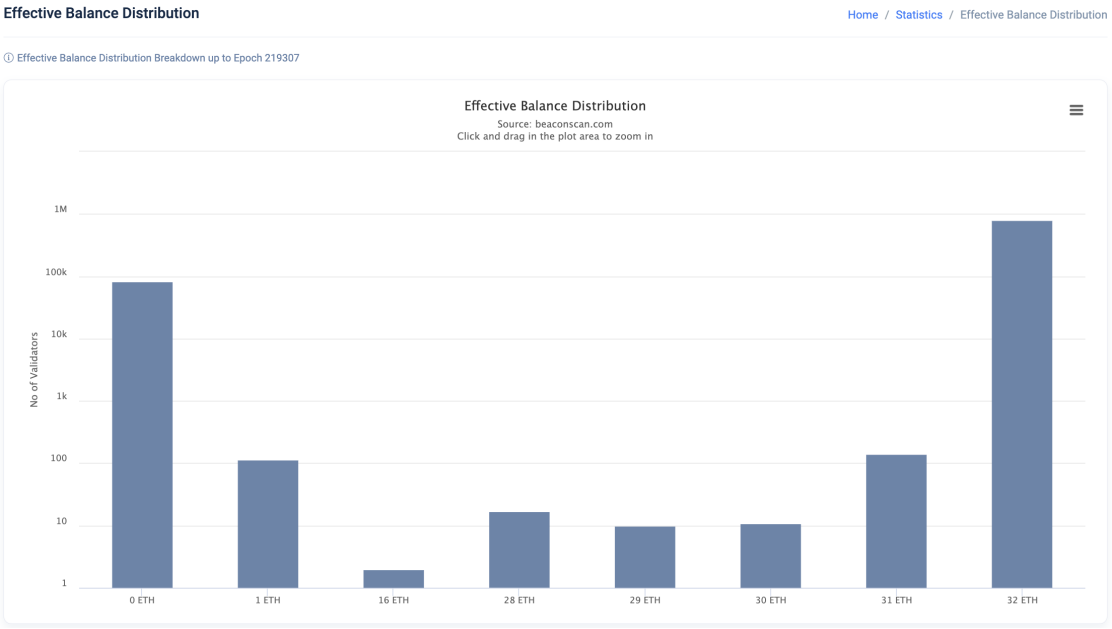


Figure 180: Bar chart of effective balance distribution. BeaconScan (3 August 2023)

Figure 181: Word cloud of top 25 graffiti text occurences. BeaconScan (3 August 2023)

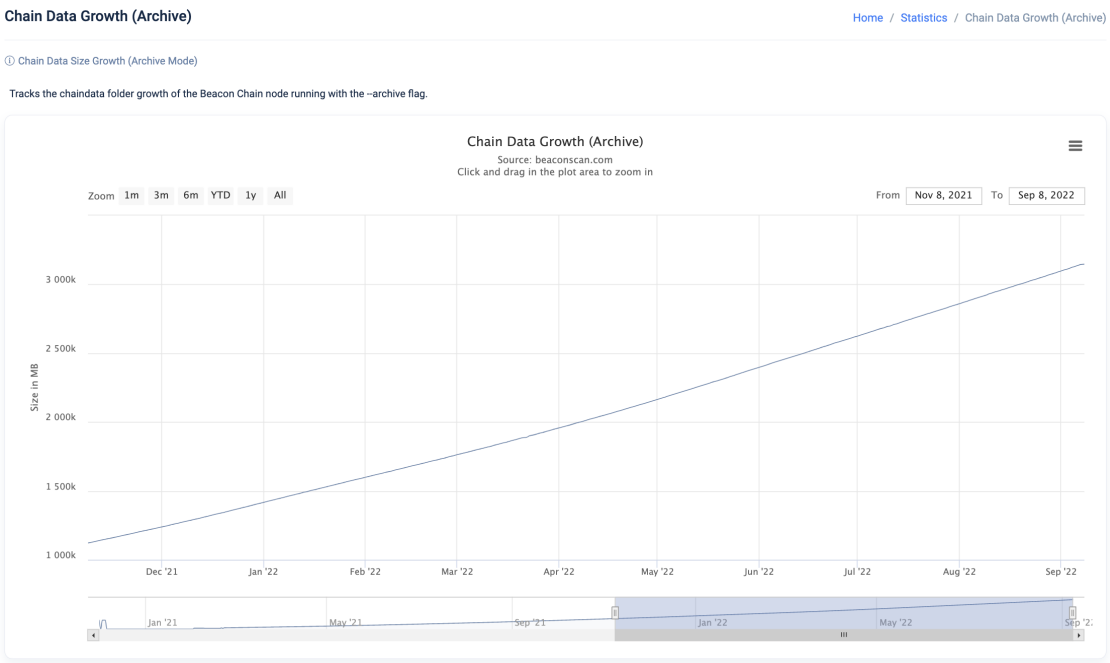


Figure 182: Line graph of chain data growth in archive mode. BeaconScan (3 August 2023)

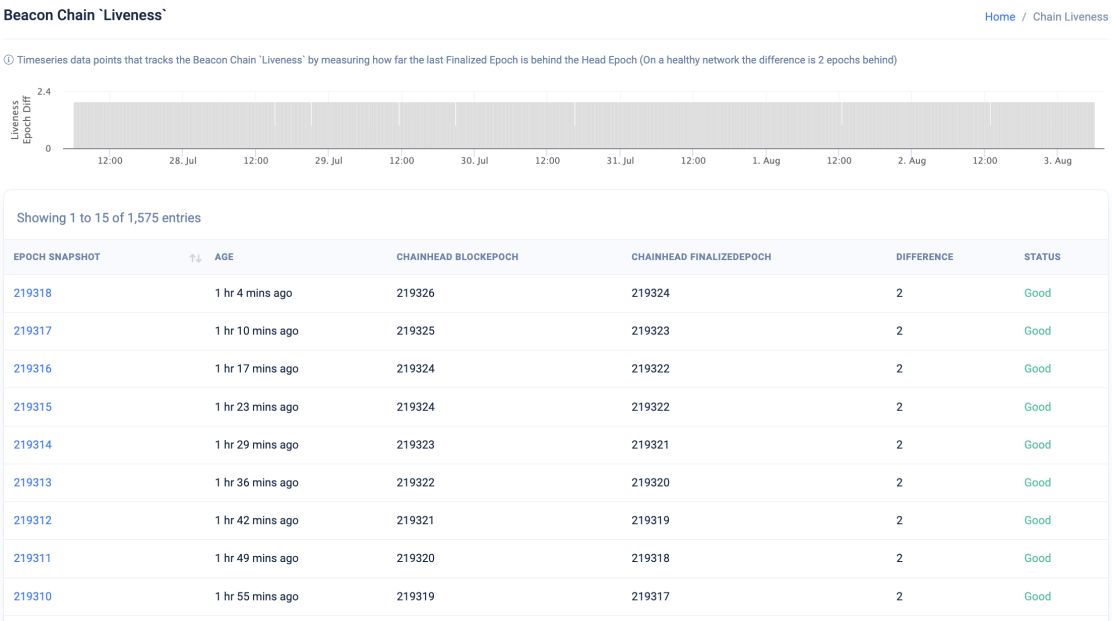


Figure 183: Time series of liveness as the difference between the last finalised epoch and the head epoch. BeaconScan (3 August 2023)

Parsec

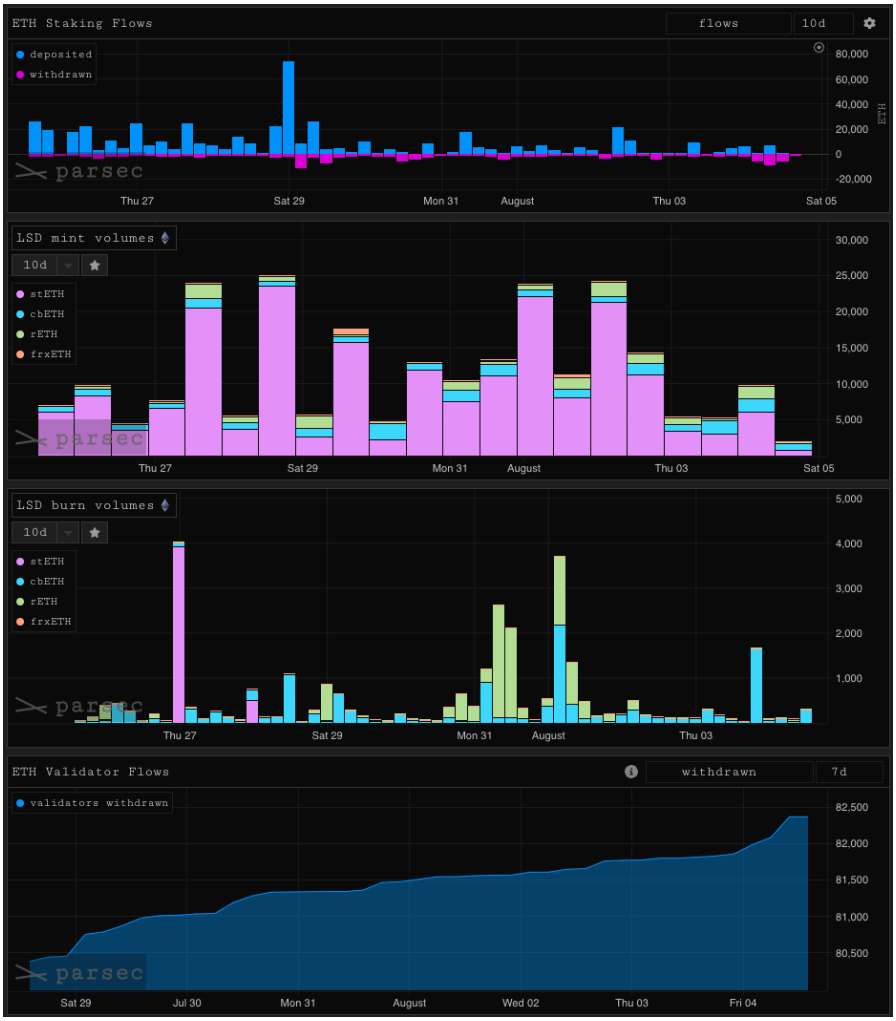


Figure 184: ETH staking flows, liquid staking derivatives mint and burn volumes, and ETH stake withdrawn by validators. Shangai dashboard by Parsec (3 August 2023)

Figure 185: Validators pending activation, price comparison Lido DAO (LDO) \ETH, Frax share (FXS) \ETH, and Rocket Pool (RPL) \ETH, Coinbase wrapped staked ETH (cbETH) discount- line graph of exchange rate and cbETH \ETH, Lido staked Ether (stETH) discount - line graph of exchange rate and stETH \ETH; graph of validators waiting to exit. Shangai dashboard by Parsec (3 August 2023)

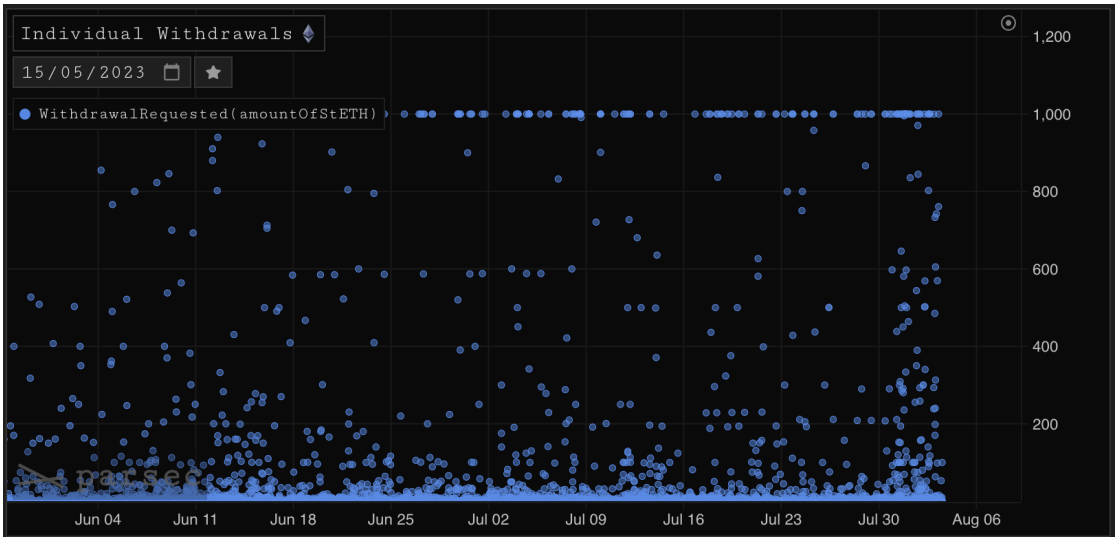


Figure 186: stETH withdrawals requested (individual). stETH Withdrawals dashboard by Parsec (3 August 2023)

Figure 187: stETH withdrawals requested (aggregate). stETH Withdrawals dashboard by Parsec (3 August 2023)

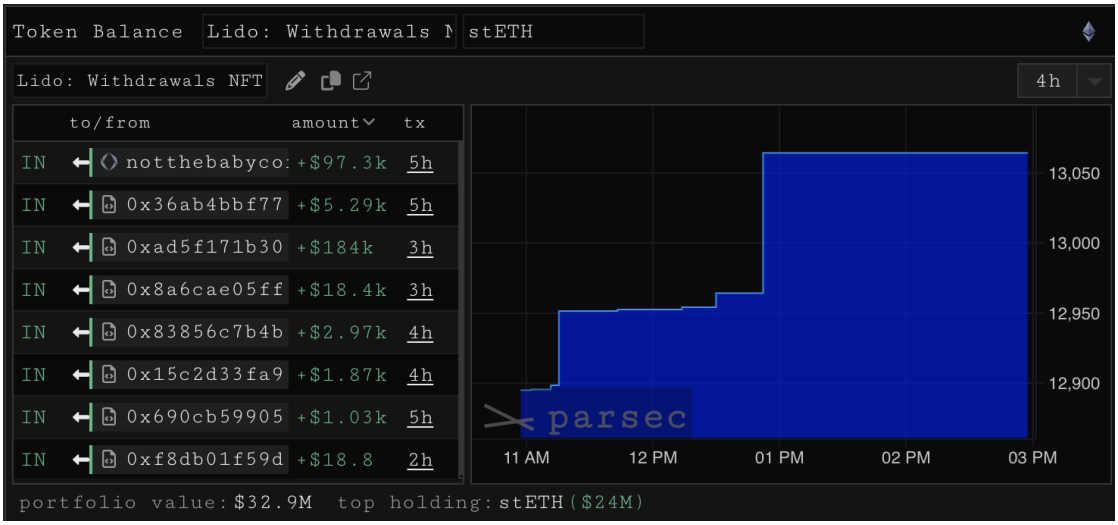


Figure 188: Token balance - Lido: Withdrawals NFT and stETH histogram. stETH Withdrawals dashboard by Parsec (3 August 2023)

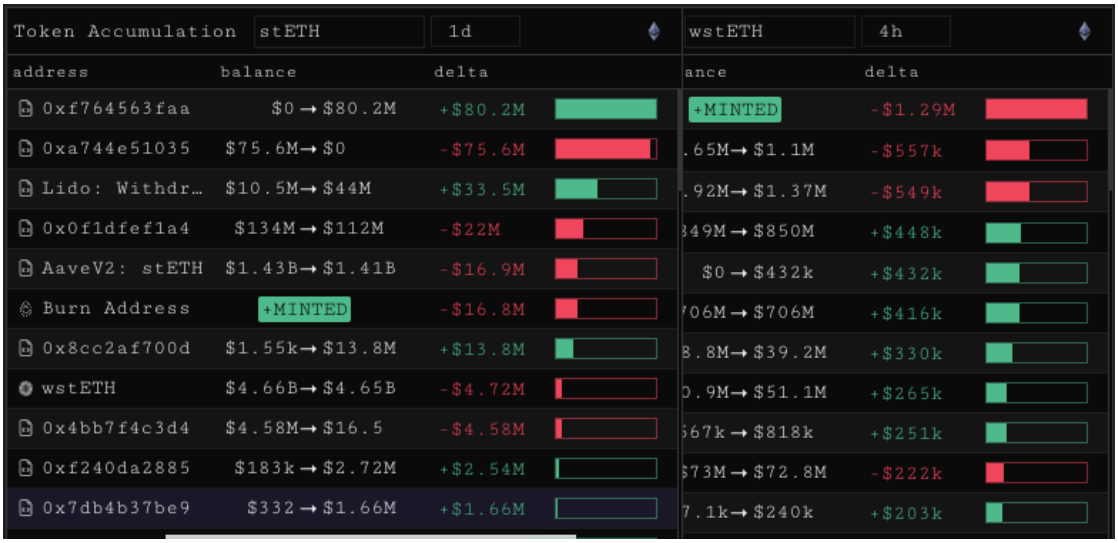


Figure 189: Token accumulation. stETH Withdrawals dashboard by Parsec (4 August 2023)

teku-besu-ohio-mainnet-archive-01

We are able to retrieve some rich data from the archive node `teku-besu-ohio-mainnet-archive-01` using API endpoints. For example, the data of the validators retrieved according to their status (as seen in the call statement) includes the *validator index, balance, effective balance, slashed flag, activation eligibility epoch, activation epoch, exit epoch and withdraw-able epoch*

- `/eth/v1/beacon/states/finalized/validators?status='active'`
  For each of the entries the sub-status is listed, i.e. 'active_ongoing', 'active_exiting', or 'active_slashed'. Alternatively a call can be made directly for one of these sub-statuses, e.g.
  `/eth/v1/beacon/states/finalized/validators?status='active_ongoing'`

- `/eth/v1/beacon/states/finalized/validators?status='pending'`
  The two sub-statuses are: 'pending_initialized' and 'pending_queued'.
  In a similar manner to the above sub-status call, we could run a query to extract only a specific sub-status:
  `/eth/v1/beacon/states/finalized/validators?status='pending_initialized'`

- `/eth/v1/beacon/states/finalized/validators?status='exited'`
  Exited status also has two sub-statuses that can be called directly: exited_unslashed and 'exited_slashed'

- `/eth/v1/beacon/states/finalized/validators?status='withdrawal'`
  Withdrawal has two substatuses: 'withdrawal_possible' and 'withdrawal_done', which can be called directly.

Graphs of validator data

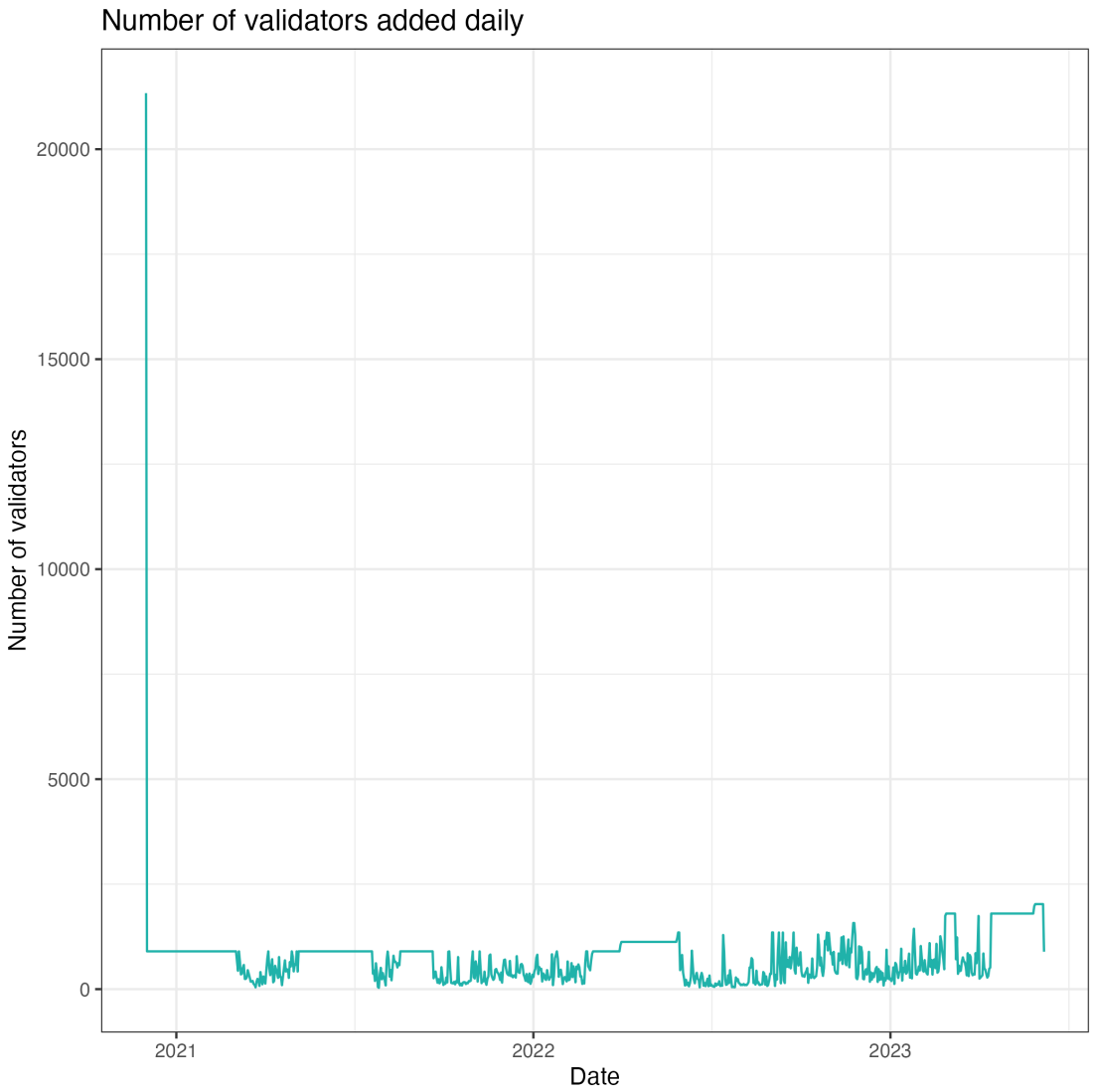


Figure 190: Number of validators added daily

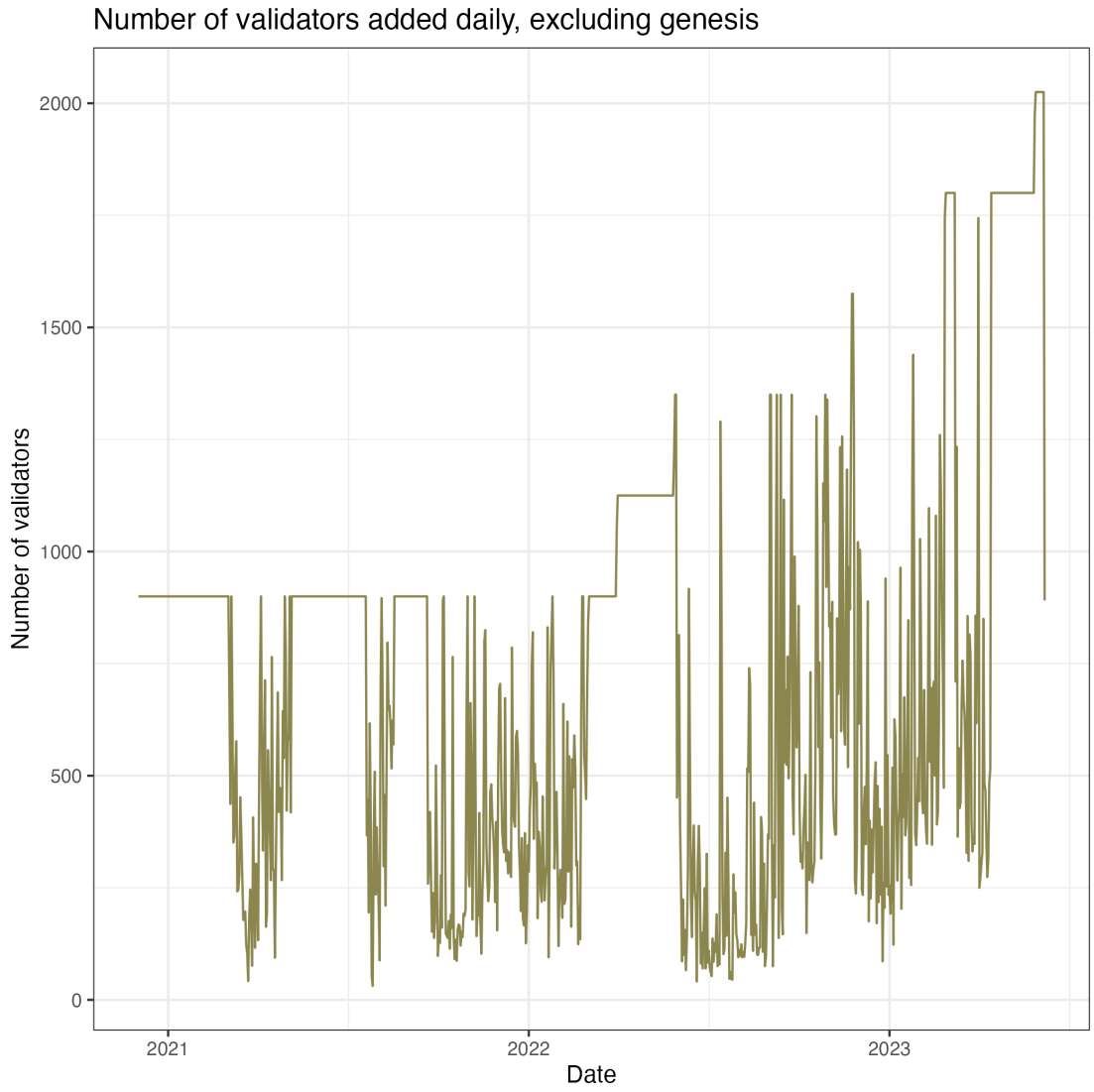


Figure 191: Number of validators added daily, excluding genesis

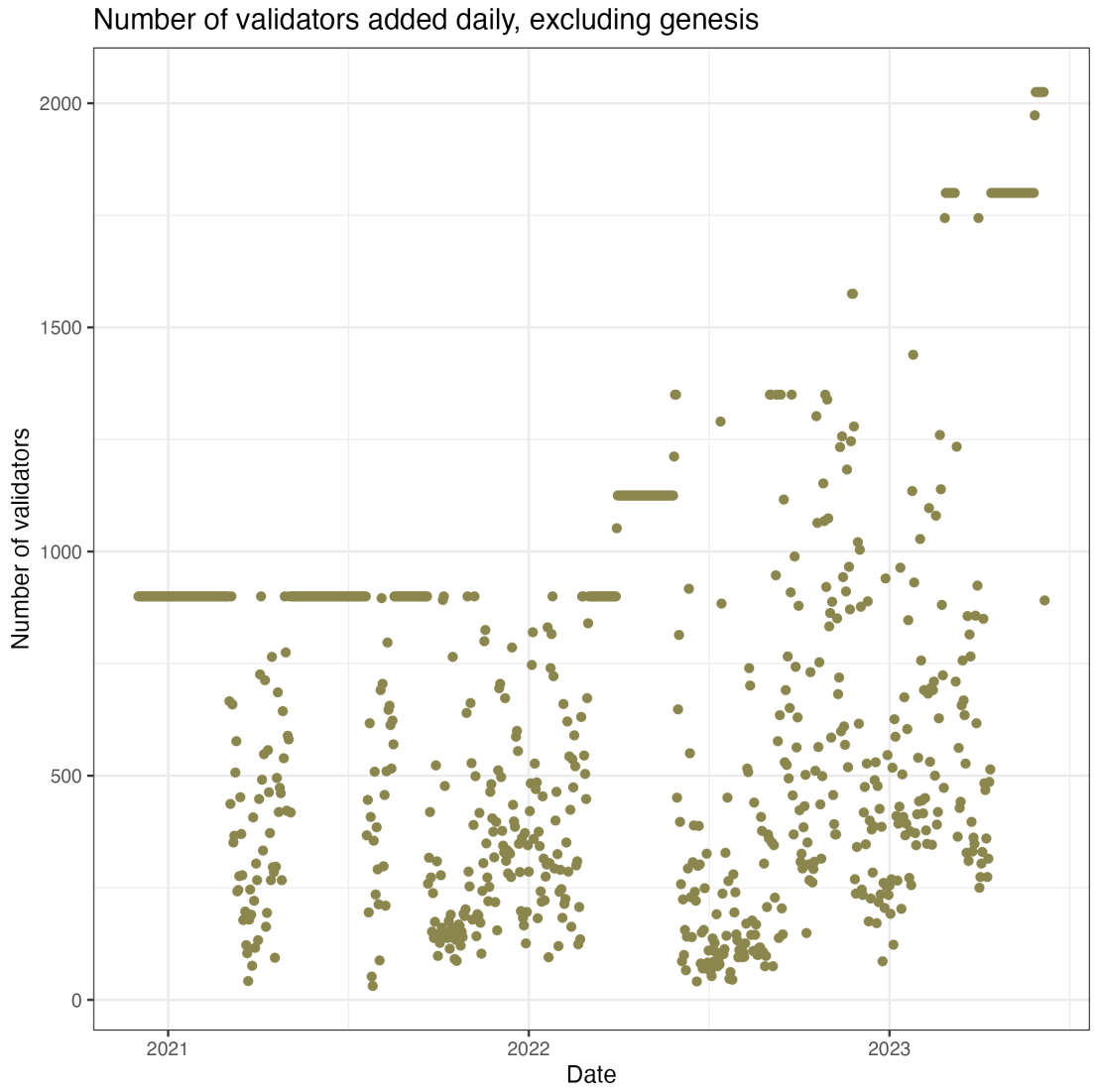


Figure 192: Number of validators added daily, excluding genesis

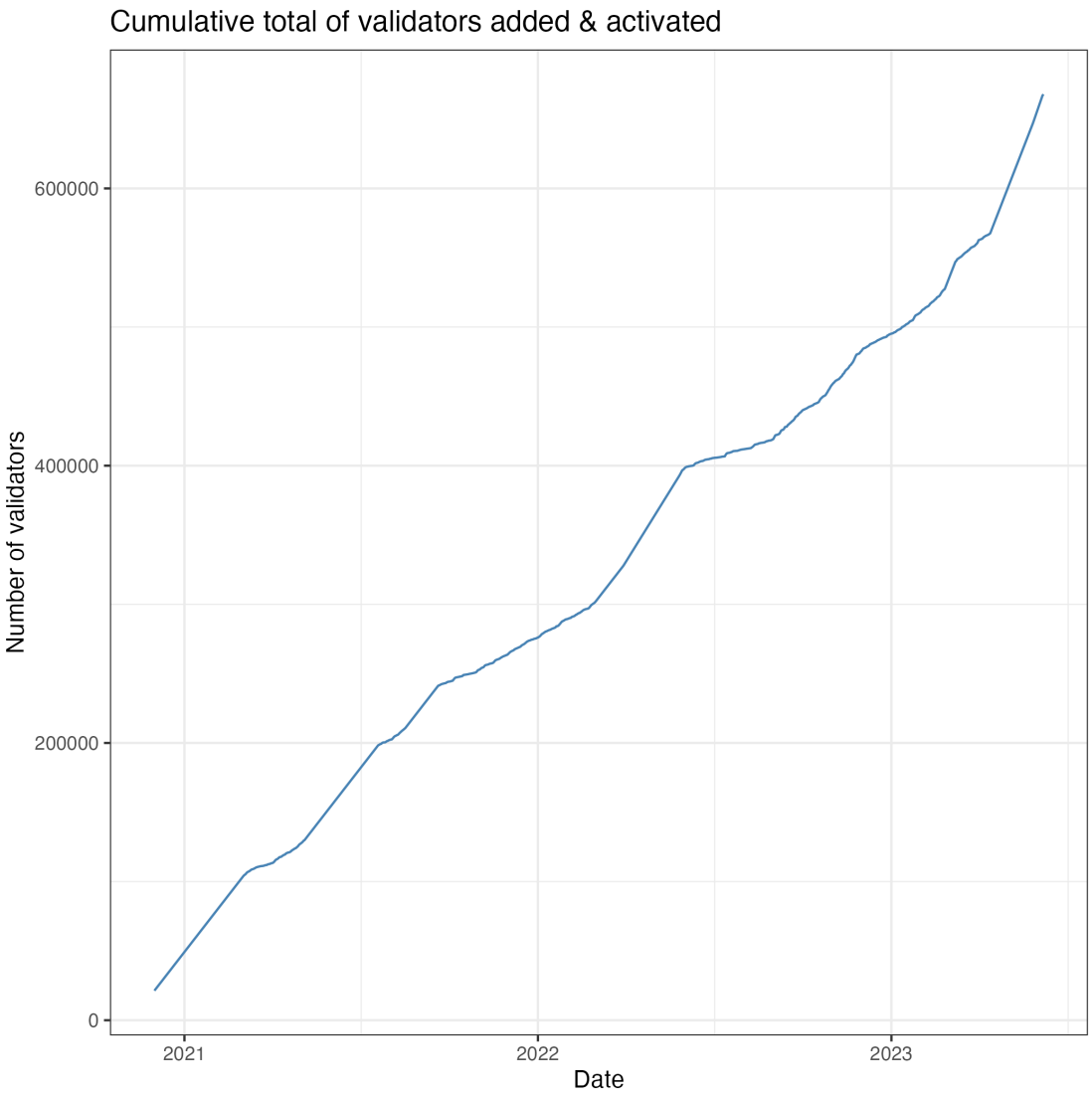


Figure 193: Cumulative total of validators added & activated

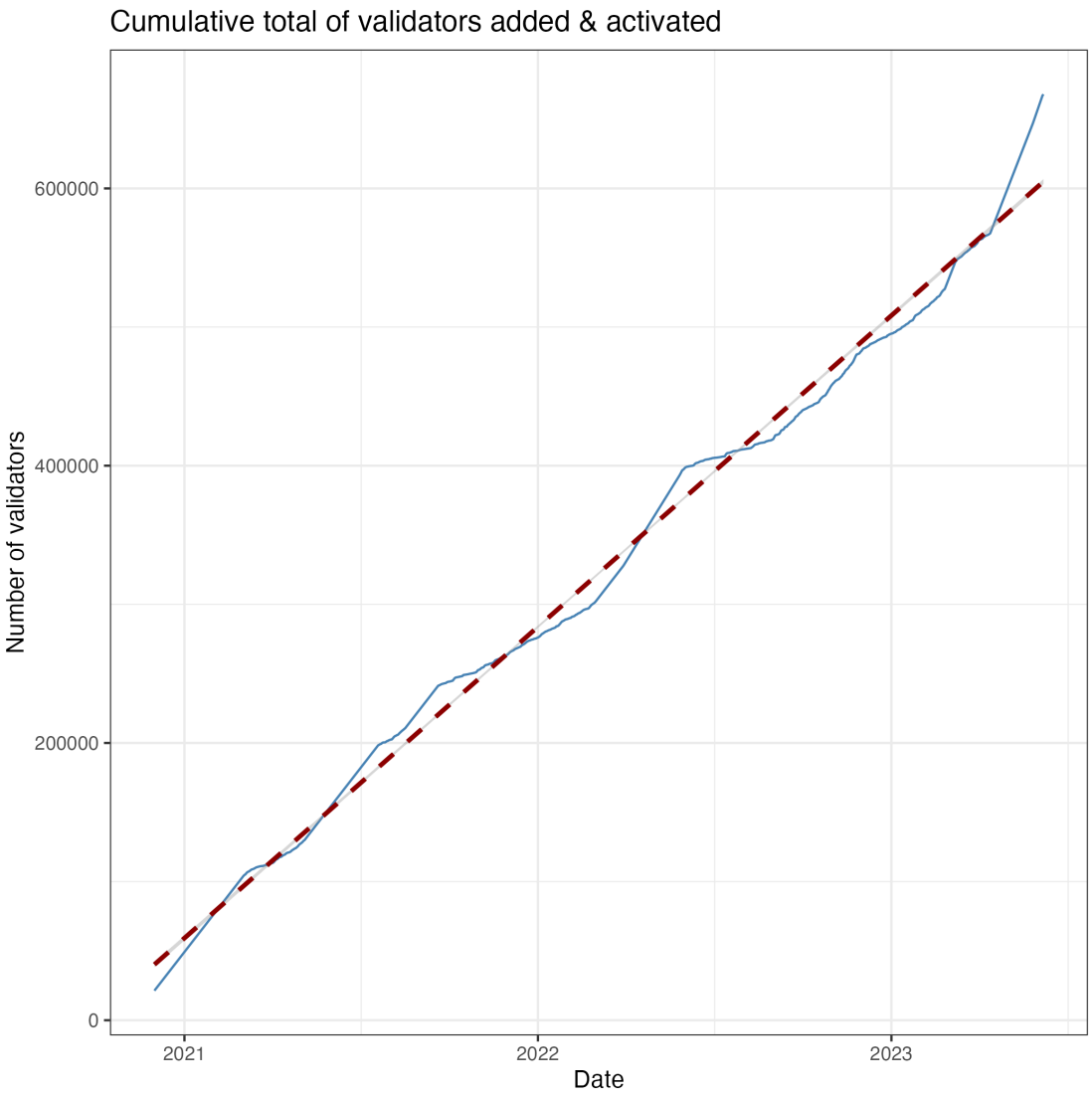


Figure 194: Cumulative total of validators added & activated with regression line fitted

5 Bibliography

References

[1] Laurence Aitchison, Nicola Corradi & Peter E Latham (2016): *Zipf's Law Arises Naturally When There Are Underlying, Unobserved Variables. PLoS computational biology* 12(12), p. e1005110, doi:10.1371/journal.pcbi.1005110.

[2] Ether alpha (2023): *Client diversity: Resource site to assist in Ethereum client diversity efforts.* Available at `https://clientdiversity.org/`.

[3] Ether alpha (2023): *Project Sunshine.* Available at `https://ethsunshine.com/`.

[4] Ether alpha (2023): *Validator queue: Dashboard to monitor validator enter/exit queues and wait times.* Available at `https://www.validatorqueue.com/`.

[5] Aditya Asgaonkar (2023): *Removing Unnecessary Stress from Ethereum's P2P Network.* Available at `https://ethresear.ch/t/removing-unnecessary-stress-from-ethereums-p2p-network/15547`.

[6] Andrew Breslin (2022): *What is staking?* Available at `https://consensys.net/blog/ethereum-2-0/what-is-staking/`.

[7] Vitalik Buterin (2017): *The Meaning of Decentralization.* Available at `https://medium.com/@VitalikButerin/the-meaning-of-decentralization-a0c92b76a274`.

[8] Vitalik Buterin (2018): *Discouragement Attacks.* Available at `https://eips.ethereum.org/assets/eip-2982/ef-Discouragement-Attacks.pdf`.

[9] Vitalik Buterin (2023): *Don't overload Ethereum's consensus.* Available at `https://vitalik.ca/general/2023/05/21/dont_overload.html`.

[10] Vitalik Buterin (2023): *Paths toward single-slot finality.* Available at `https://notes.ethereum.org/@vbuterin/single_slot_finality`.

[11] Liquid Collective (2023): *Ethereum's activation and exit queues.* Available at `https://liquidcollective.io/eth-activations-and-exits/`.

[12] Matt Corva & Bill Hughes (2023): *Staking is Data Validation, Not Investment.* Available at `https://consensys.net/blog/news/staking-is-data-validation-not-investment/`.

[13] dapplion (2023): *Ethereum specs pull request: Add upper epoch churn limit #3448.* Available at `https://github.com/ethereum/consensus-specs/pull/3448`.

[14] Benjamin Edgington (2023): *A technical handbook on Ethereum's move to proof of stake and beyond.* Technical Report. Available at `https://eth2book.info/latest`.

[15] ethereum.org (2022): *Pooled staking.* Available at `https://ethereum.org/en/staking/pools/`.

[16] ethereum.org (2022): *Solo staking.* Available at `https://ethereum.org/en/staking/solo/`.

[17] ethereum.org (2022): *Staking as a service (Saas).* Available at `https://ethereum.org/en/staking/saas/`.

[18] ethereum.org (2022): *Staking with Ethereum*. Available at https://ethereum.org/en/staking/.

[19] Etherscan (2023): *BeaconScan: The Official Etherscan Beacon Chain Ethereum 2.0 Explorer*. Available at https://beaconscan.com/.

[20] Adem Efe Gencer, Soumya Basu, Ittay Eyal, Robbert Van Renesse & Emin Gün Sirer (2018): *Decentralization in Bitcoin and Ethereum Networks*. Technical Report, Berlin, Heidelberg. arXiv:1801.03998v2.

[21] Hex (2023): *Lido on Ethereum Validator & Node metrics*. Available at https://app.hex.tech/8dedcd99-17f4-49d8-944e-4857a355b90a/app/3f7d6967-3ef6-4e69-8f7b-d02d903f045b/latest.

[22] Charles I Jones (2015): *Pareto and Piketty: The Macroeconomics of Top Income and Wealth Inequality*. *The Journal of economic perspectives* 29(1), pp. 29–46.

[23] Dániel Kondor, Márton Pósfai, István Csabai & Gábor Vattay (2014): *Do the rich get richer? An empirical analysis of the Bitcoin transaction network*. *PloS one* 9(2), pp. e86197–e86197.

[24] Qinwei Lin, Chao Li, Xifeng Zhao & Xianhai Chen (2021): *Measuring Decentralization in Bitcoin and Ethereum using Multiple Metrics and Granularities*, pp. 1–8. arXiv:2101.10699.

[25] Nansen (2023): *Eth2 Dashboard*. Available at https://pro.nansen.ai/eth2-deposit-contract.

[26] Nansen (2023): *The Ethereum Shanghai (Shapella) Upgrade Dashboard*. Available at https://query.nansen.ai/public/dashboards/Hk93n66vsO0uvycfui8ypF2xcpNhpraxfwX5AWZJ.

[27] U Natale (2022): *Analyzing Ethereum Cryptoeconomics: the validator's perspective*. Technical Report, Chorus. Available at https://docs.google.com/document/d/1r640UQOm2z-Q9nsJzqBq3BVgCtTL1_Yc7WnPp4jEBgk.

[28] Rated network (2023): *Network overview*. Available at https://www.rated.network/overview?network=mainnet&timeWindow=all&rewardsMetric=average.

[29] Mike Neuder: *EIP 7251 Maximum effective balance increase proposal [DRAFT]*. Available at https://github.com/michaelneuder/EIPs/blob/max-eb-increase/EIPS/eip-increase-maxeb.md.

[30] Mike Neuder (2023): *Increase the MAX_EFFECTIVE_BALANCE – a modest proposal*. Available at https://ethresear.ch/t/increase-the-max-effective-balance-a-modest-proposal/15801.

[31] Mike Neuder (2023): *Security Considerations and Spec Changes for a MAX_EFFECTIVE_BALANCE Increase*. Available at https://notes.ethereum.org/nHqON5l7SACkL_nPwz8Vqw.

[32] Rocket Pool (2023): *Rocket Pool: How Ethereum Staking Works*. Technical Report. Available at https://docs.rocketpool.net/guides/staking/overview.html#how-ethereum-staking-works.

[33] Roberto Saltini (2023): *Upper bound on the probability of one majority dishonest committee in the context of MAX_EFFECTIVE_BALANCE increase*. Available at `https://notes.ethereum.org/nHqON5l7SACkL_nPwz8Vqw`.

[34] James Smith & Rodrigo Vasquez (2023): *Staking survey: Key trends, take aways, and predictions*. Technical Report, Ethereum Foundation and EthStaker. Available at `https://lookerstudio.google.com/u/0/reporting/cafcee00-e1af-4148-bae8-442a88ac75fa/page/p_ja2srdhh2c`.

[35] Balaji S. Srinivasan & Leland Lee (2017): *Quantifying Decentralization*. Available at `https://news.earn.com/quantifying-decentralization-e39db233c28e`.

[36] Gavin Wood (2016): *Ethereum: a secure decentralized generalised transaction ledger*. Available at `https://github.com/ethereum/yellowpaper`.