Validation of crypto-asset on-chain transactions - relevance, risks, and challenges for official statistics

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Abstract

With the steady evolution of crypto-assets into a more mainstream phenomenon, various crypto-asset services and related business models have emerged in this field. The validation of crypto-asset transactions, especially mining/staking pools and validation-as-a-service, provides an interesting case in this context. These constructs can be seen as entities raising capital from the public to generate a common return for investors. The validation of crypto-asset on-chain transactions requires and generates the equivalents of millions of USD daily – the amounts that so far are not captured in any official statistics. This paper aims to provide insights into the latest developments in this phenomenon and to progress towards closing the statistical gap.

The first part of the paper examines the current trends and specificities of the validation of crypto-asset transactions covering mining and staking on selected blockchains as well as in Decentralised Finance (DeFi).

As the validation of transactions is largely dominated by mining/staking pools, the second part of the paper analyses these based on their geographical incorporation, business model, and governance. The objective of the analysis is to explore the relevance of the mining/staking pools and their inherent risks.

The third part of the paper elaborates on the challenges to incorporate the validation of crypto-assets in macro-economic statistics. In this context, the paper elaborates on diverse approaches to measuring country specific output of validation services and the geographical distribution of the validation fees, also providing the respective first estimates. In the collection of new data required for the estimates, the paper utilises multiple data sources, and provides a detailed analysis of the related challenges.

Keywords: Distributed Ledger Technology (DLT), Blockchain, crypto mining and staking, Decentralised Finance (DeFi), official statistics

Introduction

Crypto-assets are largely digital assets and related payment systems released as open-source software. Transactions in crypto-assets are verified by network nodes through cryptography and typically recorded in a public distributed ledger called blockchain[1]. The validation of crypto-asset transactions (crypto validation) encompasses the generation/production of crypto assets and is debated in the official statistics fora in the context of the respective classification and recording, as at present it is not covered. In general, statisticians aim to appropriately capture the output related to crypto validation involving domestic and cross country scenarios, for example when the validation is performed by residents in country A in relation to transactions between residents in country B (senders, originators) and residents in country C (receivers) (Cerutti et al., 2024).

Nevertheless, it is not an easy task for a variety of reasons. First, the crypto validation varies depending on the blockchain consensus mechanism (Binance Square, 2023). Second, the crypto validation has seen tremendous developments (mining, staking, liquid staking and re-staking) attracting millions of participants motivated by a variety of reasons. Third, the crypto validation has also featured developments in terms of business models such as validation-as-a-service or mining/staking pools. Fourth, the crypto validation mostly occurs without adhering to regulatory frameworks, resulting in lack of high-quality information, various other shortcomings, and environmental concerns (Bada, 2021).

Against this background, the first section of the paper examines the current trends, specificities, and shortcomings of mining and staking on selected blockchains as well as in Decentralised Finance (DeFi). As the validation of transactions is largely dominated by mining/staking pools (Coingecko, 2023), the second section of the paper analyses these pools based on their geographical incorporation, business model, and governance. Furthermore, this section offers commentary on the latest developments concerning validation-as-a-service. The third section of the paper delves into challenges to incorporate the crypto validation in macroeconomic statistics. In particular, it elaborates on diverse approaches to measuring/ estimating country specific output of validation services and the geographical distribution of the validation fees. Leveraging from the various indicators and data sources presented throughout the paper and in Annex 1, this section provides the first, rough estimates of country outputs and flows related to crypto validation. Furthermore, this section recalls some initiatives relevant from the data perspective in the context of crypto validation. This paper aims to showcase the diverse landscape of crypto validation and to foster a thorough discussion about the limitations and further developments of data, methodologies, and statistics.

[1] There are also some crypto-assets that are not based on blockchains.

1. The importance and shortcomings of the validation of crypto-asset transactions

1.1 Output of the validation of transactions in crypto-assets

The validation of crypto transactions and its output varies depending on the underlying method applied to adding a transaction to the next block (consensus mechanism). The most prevalent consensus mechanism remains proof-of-work (PoW), used by the two largest blockchains: Bitcoin[2] and until September 2022 – Ethereum, and several other blockchains. In the Bitcoin blockchain, the entities performing validations, known as *miners*, use their computing power to run a dedicated software to quickly solve a game of chance (PoW). Successful miners are remunerated through transaction fees and block rewards in newly minted bitcoin. With a fixed supply limit of 21 million bitcoins, set to be reached around 2140, the miners' compensation will transition to solely transaction fees. Ethereum also employed PoW until September 2022, rewarding miners similarly. Validation in Bitcoin and Ethereum collectively generated approximately USD 22.4 trillion and USD 16.5 trillion in 2022 and 2023 respectively, largely unaccounted for in official statistics (see Annex 1 Figure 1.1).

After Ethereum's transition to the Beacon Chain's proof-of-stake (PoS)[3] consensus layer, validators stake 32 ETH[4] into a smart contract, earning rewards for validating blocks, but also risking to lose their stake if they act dishonestly (validators can be "slashed"). Validator selection is random, with higher stakes increasing the likelihood of successful validation. Validators receive ETH rewards from transaction fees (referred to as "gas fees") paid by users, including a "priority fee" for computing transactions. A portion of transaction fees, the "base fee", is destroyed ("burned") to control network activity and inflation. Daily ETH issuance is around 1700 ETH, with approximately 32 million ETH staked. Furthermore, when validators are slashed, the amount they are fined is removed from circulation. There are several protocols (layer 2 solutions, sub-modules, sidechains) designed to extend the throughput of Ethereum's base layer (layer 1). For example, Arbitrum, a layer 2 solution, bundles many transactions together, puts them on the Arbitrum Virtual Machine first to execute smart

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[2] The terminology employed in this paper distinguishes between Bitcoin as the blockchain/network and bitcoin as the crypto-asset.

[3] Also other prominent blockchains employ PoS mechanism, coupled with Proof-of-History (Solana), delegated PoS (TRON) or Proof-of-Staked-Authority (BNB Smart Chain). Solana's PoS mechanism, coupled with proof-of-history (PoH), facilitates faster and cheaper transactions by embedding timestamps within transactions prior to validation, reducing block validation time. The remuneration of validators is fixed and is contingent upon their voting eligibility. The rewards they receive are determined by the amounts staked and the yield of these staked amounts, which are in turn influenced by the inflation rate and the supply of staked items.
TRON's DPoS (delegated-proof-of-stake) model allows users to vote for Super Representatives (SRs) who validate transactions, with rewards for SRs and SRs Partners based on block production and voting. Rewards are distributed among users based on their votes, constituting new TRX supply.
BNB Smart Chain employs PoSA (proof-of-staked-authority), requiring validators to be trusted nodes with token holdings at stake for selection, emphasizing both capital and reputation at risk (Binance Academy, 2024).

[4] 32 ETH is equivalent to around USD 98,5 thousands (May 2024).

contracts and transactions and then submits that transaction data back to the Ethereum. ZKSync Era and other sub-modules employ ZK Rollup, attaching zero-knowledge proofs to batches to ensure validity without waiting for finality (Goldwasser, 1989; Asher, 2021). Offloading computing load to such layer 2 solutions is integral to Ethereum's scalability strategy (Ethereum.org, 2024). Recent Ethereum updates drastically reduce the cost of processing rollup batches, lowering overall usage costs (Ethereum.org (2), 2024; L2 Beat, 2024).

Overall, annualised rewards paid to PoS validators reached USD 5.83 bn in October 2023 while market capitalisation of staked assets constitutes currently 32% of total crypto-asset market capitalisation (excluding bitcoin), significantly above the average (see Annex 1 Figure 1.2). In generally, the more crypto-assets are staked, the lower the rewards are.

The process of staking, while rewarding, is inherently illiquid. Furthermore, there instances in which entry barriers exist, such as the requirement to stake 32 ETH to validate an Ethereum transaction. To address these issues, *liquid staking protocols* allow users to stake their assets in a staking pool smart contract jointly with assets of other users, thereby reaching the minimum amount required to participate in the validation process and in the creation of new blocks of a blockchain (e.g., Ethereum, Polygon). This process is akin to that of a single validator validating transactions and running nodes in accordance with the procedure of that blockchain. In exchange, they receive a utility token that can be utilized in DeFi (e.g., exchange, lending, etc.). The rewards derived from the validation process are reinvested within the smart contract, facilitating an increase in rewards through the process of compounding. The rewards may be collected in different ways depending on the specific protocol and the blockchain in question.

An illustrative example is Lido Finance, a protocol that enables participants to stake tokens (and act as validators) on Ethereum, Polygon, the L2 ecosystem, and more. In return for their contributions, participants receive utility tokens with a 1:1 ratio with the staked assets. Consequently, for each ETH staked, users receive 1 stETH (Lido Staked ETH). Furthermore, upon receipt of a reward for staking, this reward is added to the pool, resulting in an automatic increase in the user’s balance (we refer to stETH as a “rebasing utility token”). To enhance the token's compatibility with the DeFi ecosystem, the wstETH token (Wrapped stETH) allows it to behave as a compounded token instead of a rebasing token. This means that the supply does not grow in lockstep with the growing rewards, but rather at a rate that is not necessarily linear. In contrast, the supply is fixed, and the rate evolves over time as rewards are received. These can be utilized as collateral for lending (e.g., on the Aave protocol), as liquidity on decentralized exchanges, traded for other crypto-assets, and more. Other examples of liquid staking on Ethereum include Frax Finance and Rocket Pool, the latter of which is the oldest of these protocols.

Re-staking is a process where staked assets, are used not only to secure the primary blockchain on which they are staked, but to aggregate and extend the security to other protocols[5]. This dual use of staked assets enhances their utility and potential returns. EigenLayer is the flagship re-staking application in the Ethereum ecosystem. It enables validators to use their staked ETH also to secure additional layers and protocols within the Ethereum ecosystem, thereby generating supplementary income from these secured protocols. Other applications are constructed upon EigenLayer to enhance its functionality. Ether.fi and Renzo Protocol, for instance, extend the concept of re-staking by integrating various liquid staking tokens (LSTs) from the Ethereum ecosystem and redirecting them to EigenLayer on behalf of users. They introduced eETH and ezETH as a means of representing user investments, with assets incorporating re-staking revenues through compounding. Both protocols enable users to utilize their ETH from a range of solutions, including layer 2 ones with minimal transaction fees (Ether.fi, 2024; Renzo Protocol, 2024).

While this increases the efficiency and potential earnings from staked assets, it also introduces significant risks. These include compounded exposure to slashing penalties across multiple layers or services, exposure to vulnerabilities in smart contracts, the complexities of managing security across multiple networks, and systemic risks due to leveraging staked assets, which could potentially lead to amplified effects if failures or slashing occur. Vitalik Buterin also cautions against placing undue burdens on Ethereum's validators with responsibilities beyond those associated with basic blockchain consensus. He emphasizes the potential for increased systemic risks (Buterin, 2023).

Stablecoins[6], primarily not native to their own blockchains, have their transactions validated on respective blockchains, with validators' output included in underlying blockchain indicators. For off-chain transaction validation, trading venues assign unique transaction identification codes, ensuring traceability for transactions executed off-chain.

1.2 Rationale and shortcomings of crypto validation

Miners (i.e. PoW validators) will normally mine several crypto-assets, with research showing most small miners tend to mine two of fewer crypto-assets while larger miners tend to mine six or more. According to a University of Cambridge research, the five most important criteria mentioned by miners include the market capitalisation, the price, the daily reward amount offered by a crypto-asset, reputation, and energy requirements[7] (Cambridge, 2024).

[5] E.g. oracle networks, data availability layers or blockchain bridges.

[6] In this paper we refer to stablecoins defined broadly as digital units of value that are not a form of any specific currency (or basket thereof) but rather, by relying on a set of stabilisation tools, try to minimise fluctuations in their price in such currencies (Bullmann et al. 2019).

[7] In PoS systems, the rewards from staking are generally more predictable because reward schedules are predetermined and do not fluctuate based on network difficulty and total hash power, unlike PoW. Also, the

Stakers (i.e. PoS validators) in general select crypto-assets for staking guided by similar criteria as miners, i.e. prioritizing market capitalization, asset price, and expected staking rewards for long-term profitability. While energy efficiency is a lesser concern in PoS, factors such as the security, reputation, slashing penalties, and rules of the protocol are critical. Larger validators tend to diversify their stakes across multiple networks to optimize returns and minimize risks. Furthermore, the introduction of liquid staking derivatives boosts validator liquidity, making higher market cap assets even more attractive as they often feature more robust liquid staking markets. This lowers the barrier-to-entry to the validation activities, while enhancing the productivity of staked capital. Moreover, the integration of re-staking technologies further influences validator decisions by augmenting the utility of staked assets. In blockchain systems, validation is decentralised, involving multiple participants to prevent permanent transaction censorship. However, flaws exist as the integrity relies on properly incentivising entities like miners and validators to act honestly. Validators, especially in PoS systems, can influence the transaction execution order, potentially leading to market manipulation such as front running. Large validators such as exchanges and staking pools can use their knowledge of upcoming transactions to engage in timing games (Schwarz-Schilling, 2023). These entities can delay their assigned block production times to optimize the order of transactions within a block, using these opportunities to maximise the extractable value from this reordering (i.e. MEV), which is a net loss for the system (Wahrstätter, 2024; Ethereum.org (3), 2024). Unlike PoW, where the uncertainty of block times and the high cost of delaying a block make such strategies less viable, PoS validators face less economic risk in manipulating transaction orders, raising concerns about fairness and transparency in transaction processing (Schwarz-Schilling, 2023).

The discussion on the environmental impact of Bitcoin mining has evolved, with a growing emphasis on adopting sustainable energy practices[8]. Scholarly and industry reports, such as those by KPMG, highlight the transition toward sustainable resources to reduce operational costs and contribute to Environmental, Social, and Governance (ESG) frameworks, particularly greenhouse gas emission reduction (KPMG, 2023). Initiatives prioritize clean energy sources like hydro, solar, and wind power, with examples including the conversion of methane gas into usable energy, as advocated by the World Economic Forum to align computing with climate goals (The White House, 2022; World Economic Forum, 2023).

probability of being chosen to validate a block directly depends on the publicly available staking amounts, as opposed to PoW, where the fluctuating computational power can unpredictably affect probabilities.

[8] Some bitcoin enthusiasts demonstrate that Bitcoin consumes at least 28 times less energy and can run today with 60 times less energy than the classical system. At a single transaction level and with total volumes accounted for, Bitcoin produces equivalent energy efficiency rates or better. When Bitcoin Lightning is compared to Instant Payment scheme, Bitcoin gains exponentially in scalability and efficiency, proving to be millions of times more energy efficient per transaction than Instant Payments. See e.g.: Datta, Bikramaditya and Hodor, Idan, Cryptocurrency, Mining Pools' Concentration, and Asset Prices (January 12, 2024). Available at SSRN: https://ssrn.com/abstract=3887256 or http://dx.doi.org/10.2139/ssrn.3887256

Local initiatives reflect a broader impact of Bitcoin mining on community development and environmental sustainability. In Texas, the surge in renewable energy facilities, partly driven by Bitcoin mining's energy demands, enhances energy diversity (Lal, 2023). Similarly, projects such as those at Virguna Park in Central Africa employ the park's hydroelectric resources to both conserve the ecosystem and facilitate Bitcoin mining, showing a model of environmental and economic harmony (Popescu, 2023). In the urban context, North Vancouver is testing the integration of Bitcoin mining's excess heat in municipal heating solutions, in partnership with MintGreen and Lonsdale Energy Corporation (Willms, 2021).

These efforts collectively suggest that Bitcoin mining could support the renewable energy sector. By catalysing demand for excess energy, it enhances the viability of sustainable energy initiatives financially and operationally. This transition, which moves the Bitcoin from a major energy consumer to a contributor to the development of sustainable energy solutions, could elevate the sector and pave the way for energy consumption models that balance economic viability and environmental protection.

2. Beyond solo validating, validation as a service, mining and staking pools, and other

2.1 Business models and shortcomings of mining, staking and cloud pools

The evolution of Bitcoin and other crypto-assets that employ the PoW consensus algorithm has witnessed considerable advances. Initially, mining was feasible with CPUs in standard computers, but it has since transitioned to more efficient Application-Specific Integrated Circuits (ASICs). These specialised chips markedly enhance mining efficiency, yet have also prompted concerns about centralisation due to their high costs and operational requirements (Gingerich, 2024; Bitcoininsider, 2023; Speakman, 2023).

Mining pools have emerged as a prevalent solution for miners confronting heightened difficulty and resource demands. These pools aggregate resources in order to improve the chances of earning rewards, distributing these based on contributions through methods such as Pay-Per-Share (PPS) and Pay-Per-Last-N-Shares (PPLNS). However, this aggregation has raised concerns about the potential centralisation of mining power, which could compromise network security (Arslanian, 2022). The success of mining pools depends on various factors, including reward distribution methods, fee structures, security measures, server stability, and community engagement. It is of the utmost importance that transparency and robust support are in place in order to build trust and retain miners, which in turn enhances a pool's competitiveness and sustainability (Binance Academy, 2020; Williams, 2024).

Staking pools in PoS blockchains allow participants to combine resources for a higher chance of block validation rewards. These pools are more energy-efficient and accessible than

PoW systems, but they face their own risks of centralisation, which could potentially affect the blockchain's integrity (Gersbach et al., 2014; Skrill, 2024; Arpornthip, 2024; Das, 2023).

Cloud mining represents an accessible pathway into the crypto-asset mining scene, allowing users to participate without direct hardware management. This method reduces the environmental impact of mining and lowers entry barriers, but users must consider the cost-effectiveness and long-term investment returns (Kucoin, 2024; Khazzaka, 2022; Appendino et al., 2023; Kraft, 2022; Cambridge, 2024).

The continuous evolution of crypto-asset mining technologies and business models reflects the necessity to achieve a balance between efficiency, accessibility, security, and decentralisation within the mining industry. Furthermore, the possibility for members to switch between these mining pools and the decentralised structure of the majority of pools prevent a single pool from attaining a dominant market position (Ramos et al., 2021; Datta et al., 2024; FasterCapital, 2024).

2.2 Geography, Sustainability and Governance of a crypto mining operation

The success of a crypto mining operation is contingent upon a multitude of external factors, with geography playing a pivotal role in its efficiency and sustainability. Mining operations frequently select locations based on their proximity to affordable and plentiful energy sources, such as hydroelectric or geothermal power. For instance, Sweden's frigid climate and abundant hydropower make it an optimal location for cost-effective and sustainable mining. Similarly, regions in South America utilise geothermal energy from volcanic activity, which also provides a stable power supply while minimising environmental costs. The regulatory environment also affects where mining pools are set up, as countries with renewable energy incentives attract miners, while those with strict regulations or high energy taxes may deter them. These geographic considerations not only influence operational costs and strategies but also promote the dispersion of mining activities globally, aiding in the decentralisation of mining power and enhancing network security (Appendino et al., 2023; Kraft, 2022).

The governance of mining pools can vary considerably, with decisions sometimes made unilaterally by individuals or through collective operator consensus. A minority of pools involve users in governance decisions through mechanisms such as vote-by-CPU, reflecting differing levels of user engagement and policy transparency. Furthermore, the rise of validation-as-a-service programmes, as exemplified by centralized exchanges such as Kraken, introduces new models of participation. These programmes offer returns on staked crypto assets, yet they also raise concerns about investor control and regulatory compliance. This is evidenced by the legal challenges faced by Kraken with the SEC over unregistered securities (SEC, 2023).

In conclusion, the geography, regulatory environment, and innovative business models, such as staking as a service, significantly influence the sustainability, governance, and overall success of crypto mining operations. It is worth noting that while blockchain networks are often the subject of criticism for their high energy consumption, they offer several efficiencies that can, under certain conditions, lead to a reduction in the energy use per transaction when compared to traditional financial networks. These efficiencies are derived from the direct, decentralised and optimised nature of blockchain transaction processing (Khazzaka, 2022).

2.3 The landscape of staking and mining pools

There are over 100 mining pools for bitcoin and other crypto-assets, but their distribution and activity levels vary significantly (MiningPoolStats, 2024). The top 1% of contributors in a typical pool provide one-third of the pool's total computational power (“hash power”/”hash rate”), while all active[9] members contribute about 68%. Despite China's official ban on Bitcoin mining[10], it still plays a significant role in funding U.S. mining operations, benefiting from the use of regional power providers. Historically, until June 2021, 65% of global mining was concentrated in China, particularly in Sichuan due to its hydropower resources. As of January 2022, the United States is leading in crypto mining hash rate share, with China still maintaining a strong presence despite a decline in its global ranking (see Annex 1 Figure 2.1) (Cambridge, 2024).

In terms of staking, as reported by Stakingrewards.com, staking providers manage assets totalling approximately USD 116.7 billion. Among the 450 staking providers analysed, 189 are considered global, accounting for 40% of total Assets Under Management (AUM) (see Annex 1 Figure 2.2). The remainder is distributed across 50 countries, with the U.S., Switzerland, and Germany hosting most of the services. A total of approximately 54.4 million unique wallet addresses are involved in staking activities (StakingRewards, 2024).

The data on companies involved in crypto transaction validation is less straightforward to parse, as many datasets lack clear labels identifying relevant companies. However, an analysis using Crunchbase has identified around 1,000 companies engaged in mining, staking, and related activities (see Annex 1 Figure 2.3). According to this data provider the funding received by these companies may be indicative of their respective shares in the total mining and staking activities. It is assumed that greater funding levels are associated with higher output.

[9] Most pools consider hashers to be active when they contribute hash power at least once a week.

[10] On 24 September 24, 2021, the Chinese authorities issued a circular to local governments on how to wind down crypto-asset mining activities in their areas.

3. Validation of transactions in crypto-assets in official statistics

3.1 Challenges for macroeconomic statistics

The crypto validation is a relatively new economic activity and not easily comparable with existing activities, thus discussions about its appropriate classification are ongoing and it has not yet been included in macroeconomic statistics.[11] Consequently, it is important to consider how to accurately measure and account for it. By leveraging blockchain data, one can access pseudonymous[12] information regarding the transaction sender and the validator who validates this transaction. However, transforming this information into precise statistics at a national level is incredibly difficult because of the lack of geographical attribution of blockchain addresses (both for senders and validators).[13] However, companies that specialise in blockchain intelligence allocate significant resources to identify some entities, with a primary focus on major players such as centralised exchanges, mining pools, thereby facilitating their geographical attribution. Companies operating as validators can be traced through national business registers or other databases, facilitating the extraction of further details regarding their output and costs, but rarely about the counterparties of validated transactions. Another issue is whether it is appropriate to assign a particular country to a validator, when the validation is pooled or provided as-a-service by a number of ultimate validators residing in various other countries. Similarly, a transaction sender (e.g. a CEX) might record on-chain net of transactions involving a number of senders from various countries.

There are several methodologies which aim to estimate geographical flows of crypto-asset transactions which might be helpful in gaining insights into the country redistribution of validation fees.[14] However, all of them are subject to limitations that could affect their representativeness and value for statistics.[15] Estimates of the geographic distribution of crypto-asset flows, which are often not replicable, vary significantly depending on the methods and assumptions used indicating that there is a lot of uncertainty. For example, the Chainalysis methodology provides a geographic breakdown for around USD 2.3 tn (USD 14 bn net) of on-chain crypto-asset transactions in 2023 (see Annex 1 figure 3.1). These flows are allocated to

[11] Macroeconomic statistics include a wide range of key statistics for the economy e.g. of a country as a whole and for its individual sectors, the relationships between sectors, and the transactions between residents and non-residents.

[12] There are also some blockchains that offer anonymity.

[13] An additional challenge arises from the necessity of performing complex calculations separately for each blockchain of interest, as the analytical tools cannot be easily transferred.

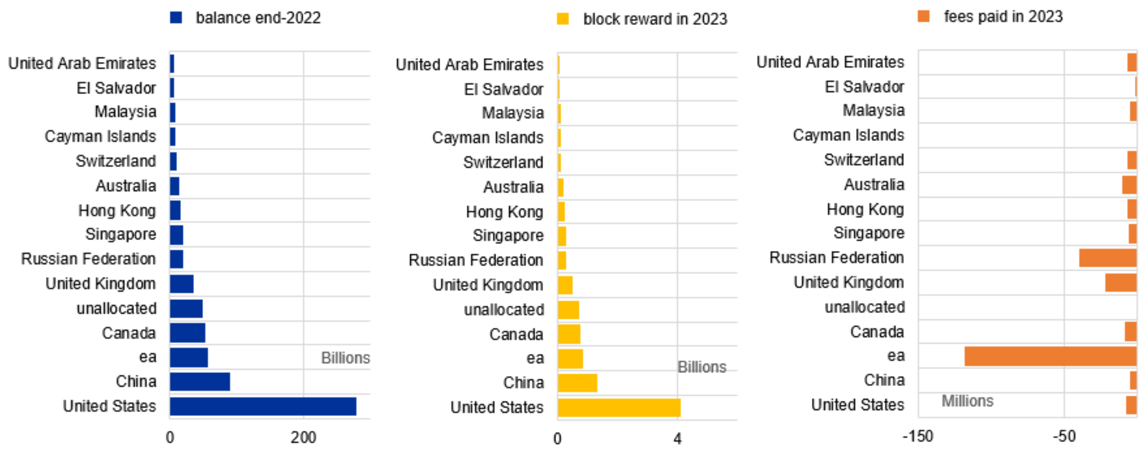
[14] e.g. for estimating the country distribution of senders transacting directly on-chain or via CEXes, as well as of ultimate validators via staking providers' services.

[15] These limitations primarily arise from the opacity of crypto-asset trading platforms in light of their lack of regulation (or insufficient compliance with existing regulations) and associated reporting requirements; and the pseudonymous nature of blockchain data, which presents challenges in identifying the geographic location or country residence of the parties to a crypto-asset transaction.

countries based on the location of visitors to the websites[16] of crypto-asset trading platforms and DeFi protocols. Crystal and the BIS Innovation Hub Eurosystem Centre Project Atlas use a similar methodology to that of Chainalysis but allocate on-chain flows according to the country in which a trading platform is registered rather than the location of its users. This provides a different perspective – and trend - as users may not be located in the same country as their trading platform. Notably, a significant share of crypto-asset activity originates from platforms based outside of major jurisdictions, including in the Seychelles and the British Virgin Islands. Binance trading platform, which accounts for a larger share of activity than any single country, does not have a clear country of incorporation. Geographical breakdowns of off-chain transactions on centralised exchanges can by proxied by taking trades involving fiat currencies.[17] This approximation method has serious limitations as most off-chain transactions involve only crypto-assets. Moreover, transacting in a fiat currency is usually not limited to users residing in the country of issuance.

Validators incur expenses associated with their service. On PoW blockchains the costs are linked to the energy consumption. Although it's not possible to obtain the exact cost for each validator, a rough estimate indicates that the electricity expenses for mining bitcoin in 2023 might have accounted for 69% of the total mining reward, compared to 33% in 2022 (see Annex 1 Figure 3.2). When using validation-as-a-service on PoS blockchains, commission fees are involved and depend on the amount staked (Revolut, 2024).[18]

Figure A Selected country distribution of BTC mining balances, block rewards and fees



Source: Crunchbase, Chainalysis, Cambridge Centre for Alternative Finance, and authors' calculations. Notes: Cost of mining is fixed at 66% of mining rewards and subtracted from the figures on the chart. Aggregated

[16] Web traffic refers to the volume of viewers visiting a website regardless of whether they utilise the crypto-exchange service.
[17] Based on CryptoCompare, the dominant currency for off-chain trading of BTC and ETH is USD, followed by JPY, KRW, EUR, and AUD. Trades using any other fiat currency beside the top 10 are small.
[18] e.g. Revolut offers staking programme covering ETH (Ethereum), ADA (Cardano), DOT (Polkadot), XTX (Tezos), SOL (Solana) and MATIC (Polygon). Commission fess range between 15% and 35% depending on the staked amount and are lower if the staked amount exceeds the average threshold of 4.000 USD.

balances and block rewards from Chainalysis were broken down by country using average shares calculated based on Crunchbase and CCAF information on the geographical location of mining pools. Aggregated fees from Chainalysis were broken down by country using shares based on Chainalysis cross-country flows. Estimates covering mining and staking are available for all countries, while this chart for presentational reasons focuses on selected countries.

Despite the challenges surrounding crypto validation data availability for macroeconomic statistics, it is still possible to provide (rough) estimations. Figure A provides an overview of the approximate bitcoin mining balances, block rewards, and fees in selected countries. This initial effort to create macroeconomic statistics using the available data aims to foster a more thorough discussion about the limitations of the data and other areas that need improvement or further development. It might be helpful if statisticians would engage in more "hands-on" work involving blockchain data. Furthermore, this community should consider whether they should create their own methodologies for country attributions, especially with the potential benefits of new initiatives that can improve data quality (see section 3.2).

3.2 Initiatives to address data gaps

There are a few initiatives which may in the future contribute to increased data availability supporting the development of statistics concerning crypto assets in general, and crypto validation in particular. First, the latest revisions to the two statistical classifications of economic activity[19] (United Nation Statistics Division, 2024a; Eurostat, 2023, European Commission (2023)) both relevant for the preparation of macroeconomic statistics – analysed crypto-asset activities and whether they could warrant dedicated entries in the classification (IFC Working Group on Fintech Data Issues, 2020). While analysed activities eventually did not earn any dedicated entry in the classification systems (von Kalckreuth et al., 2022) the explanatory notes were revised to include them to the extent possible. For example, the validation and mining for crypto assets that are deemed financial assets should be included in the *NACE Rev. 2.1 Code: 66.19 Other activities auxiliary to financial services, except insurance and pension funding* of section K (Finance and insurance activities). Therefore e.g. staking related to stablecoins with liability attached which are issued on the Ethereum blockchain should fall into financial activities, while bitcoin mining would be classified elsewhere. However, as mining/staking pools continue to gain prominence in crypto validation, one may question whether their activities should eventually be classified as financial. Mining pools can be seen as entities raising capital from the public to generate a common return for investors (collective investment undertakings). This activity entails aggregating capital from

[19] the International Standard Classification of All Economic Activities (ISIC) and the statistical classification of economic activities in the European Community (NACE).

multiple investors to invest based on a specified investment policy, managed by third parties, code, algorithms, or smart contracts. Investors generally lack control over the daily management of the mining pool. A similar approach could be considered with respect to activities of providers of the validation-as-a-service, as exemplified by the SEC charges concerning the Kraken Staking Programme as described in section 2.1.

Second, the concepts and accounting standards for compiling macroeconomic statistics[20] (United Nation Statistics Division, 2024b; IMF, 2024) are currently under revision which includes, among other topics, the treatment of crypto assets. A part of the statistical community[21] released for global consultation the guidance notes (GN) discussing the recording of crypto assets in macroeconomic statistics. While this GN does not cover the issue of recording of crypto validation, it offers detailed insights into a variety of data that are required for statistical purposes and are recommended for countries to start collecting. This forum is currently working on recording crypto validation in macroeconomic statistics.

Finally, a significant milestone in the regulatory landscape is the implementation of the Markets in Crypto-assets Regulation (MICAR)[22] within the European Union[23]. This regulation focuses on crypto-asset issuance and service provision, and its implications extend to future data availability concerning crypto validation. MICAR draws some attention to the adverse climate impact and environmental issues related to crypto validation and prescribes deploying more environmentally friendly solutions and ensuring that any adverse impact in this context is adequately identified and disclosed by issuers of crypto-assets and crypto-asset service providers.[24] Crypto validation is not regarded as crypto-asset service, therefore the information about staking/mining pools or other entities offering validation-as-a-service might not be available in the European Securities and Markets Authority (ESMA) register. However, ESMA in cooperation with the European Banking Authority (EBA) are in charge of developing draft regulatory technical standards (RTS) to specify, in the context of climate and environmental adverse impact, the content, methodologies and presentation of information, and to outline key energy indicators for ARTs and EMTs. This information could prove beneficial in improving the estimation of mining/validation output.

[20] National accounts (the System of National Accounts, SNA 2008), see the UN website, and external sector statistics (the Balance of Payments and International Investment Position Manual, Seventh Edition, BPM7, see the IMF website.

[21] The IMF Committee on Balance of Payments Statistics and the Inter-secretariat Working Group on National Accounts.

[22] Regulation (EU) 2023/1114 of the European Parliament and of the Council of 31 May 2023 on markets in crypto-assets, and amending Regulations (EU) No 1093/2010 and (EU) No 1095/2010 and Directives 2013/36/EU and (EU) 2019/1937.

[23] MICAR regulates activities related to (i) offering crypto-assets such as asset-referenced tokens (ARTs) and electronic money tokens (EMTs) to the public, (ii) seeking admission for trading, as well as (iii) issuing such tokens. MICAR came into force on 29 June 2023.

[24] Having regard to the principle of proportionality and the size and volume of the crypto-asset issued.

Conclusions

This paper has explored the intricate landscape of crypto-asset transaction validation, illuminating its growing relevance in the financial ecosystem and the associated risks and challenges it presents to official statistics. The advent of crypto-assets as a mainstream financial phenomenon necessitates the development of a robust statistical framework that accurately captures the economic activities associated with their validation.

There are various facets of the crypto-asset validation process, including its operational dynamics across different consensus mechanisms and its integration into new business models such as mining and staking pools, as well as validation-as-a-service. These developments serve to illustrate the intricate and rapidly evolving nature of the blockchain technology that underlies crypto-assets. Furthermore, the geographical distribution and economic impact of these activities serve to illustrate the global nature of the crypto market and the decentralised essence of blockchain technologies.

Nevertheless, significant obstacles remain in incorporating these activities into macroeconomic statistics. The pseudonymity and lack of geographic attribution inherent in blockchain technology present significant challenges to the precise measurement of these activities. The current methodologies and data sources offer only a partial view, which is fraught with uncertainties and limitations in its representativeness.

The initiatives discussed, such as the integration of crypto-asset activities into the NACE Rev. 2.1 Code and the ongoing revisions of macroeconomic statistical standards, signal a progressive acknowledgment of the importance of these activities within the broader economic landscape. Moreover, the discourse on regulatory frameworks, particularly the Markets in Crypto-assets Regulation (MICAR), offers a promising perspective for enhanced data accessibility and an increased comprehension of the environmental consequences associated with crypto validation.

In conclusion, as the crypto-asset sector continues to mature and evolve, it is imperative for statistical methodologies and regulatory frameworks to adapt and innovate. In order to ensure the accuracy and comprehensiveness of statistical data, it is crucial to engage more deeply with blockchain data, refine geographic attribution methodologies, and enhance the transparency of crypto-asset transactions. These efforts will not only improve the accuracy and comprehensiveness of statistical data but also ensure that the financial system remains robust and responsive to the innovations brought forth by crypto-assets.

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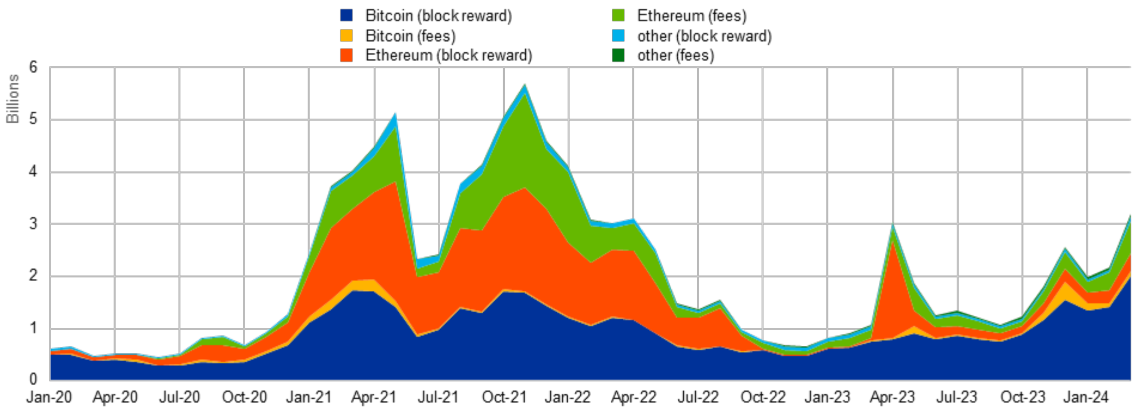
Annex 1 Charts

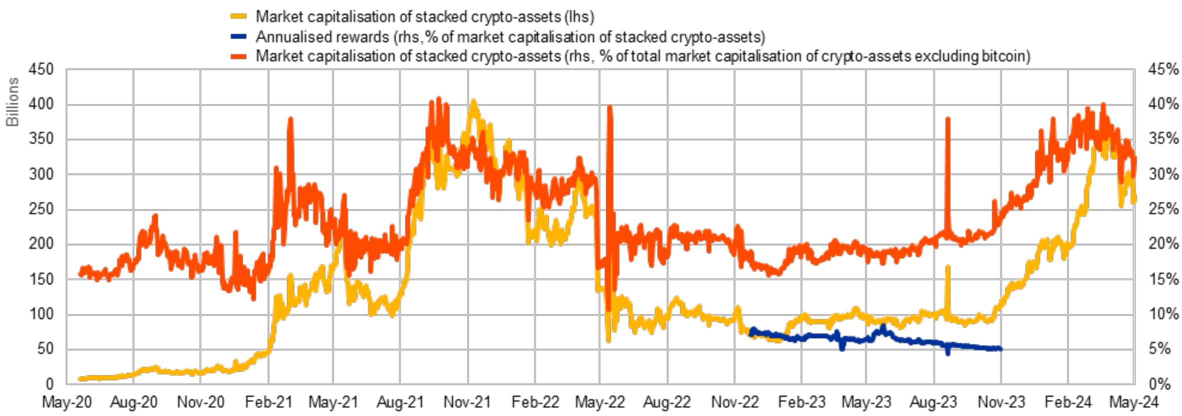
Section 1

Figure 1.1 Validation revenues for Bitcoin and Ethereum (USD, monthly)



Source: Chainalysis and authors' calculations. Notes: Validation revenues are valued at market prices of respective crypto-assets.

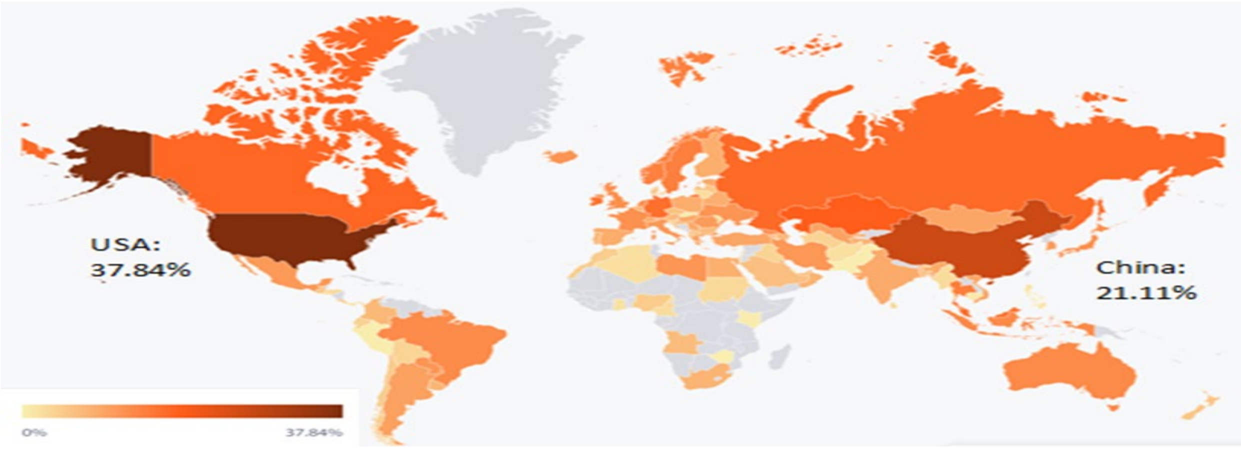
Figure 1.2 Total rewards paid out to stakers



Source: Stakingrewars.com and authors' calculations.

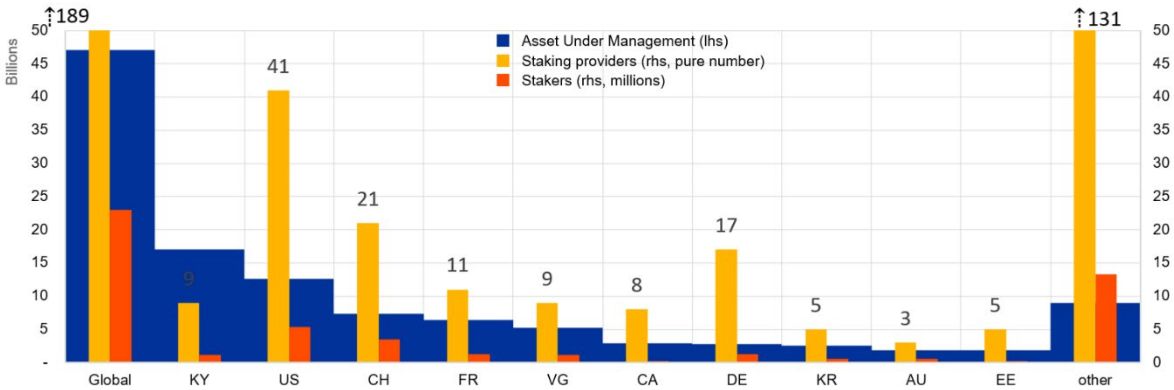
Section 2

Figure 2.1 Average monthly hashrate by country



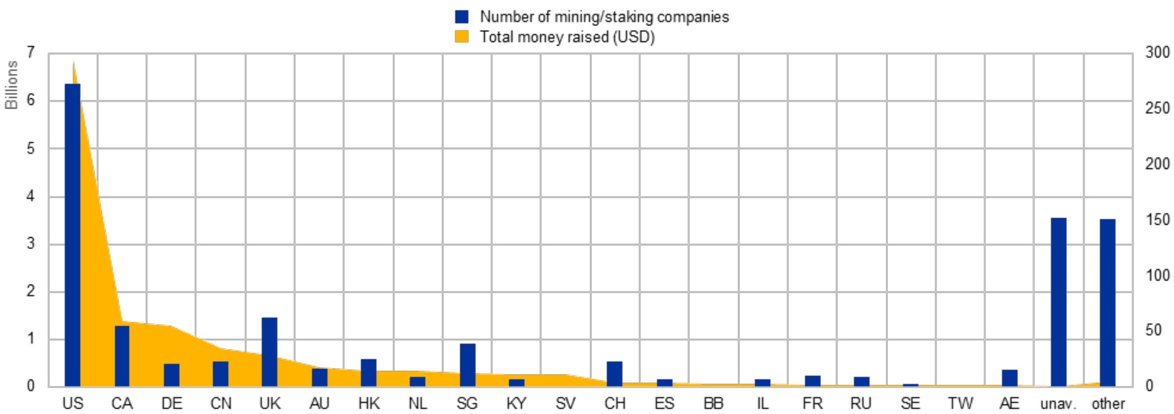
Source: Cambridge Centre for Alternative Finance (CCAF.io)

Figure 2.2 Staking landscape (AUM, number of staking providers and number of stakers)



Source: Stakigrewards.com and authors' calculations.

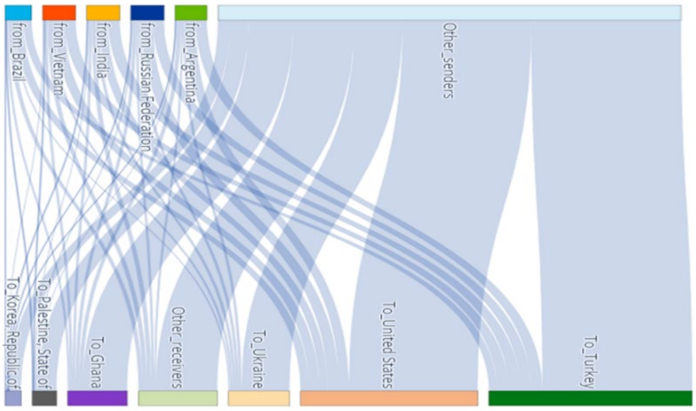
Figure 2.3 Companies in involved in mining/staking and related activities



Source: Crunchbase and authors' calculations.

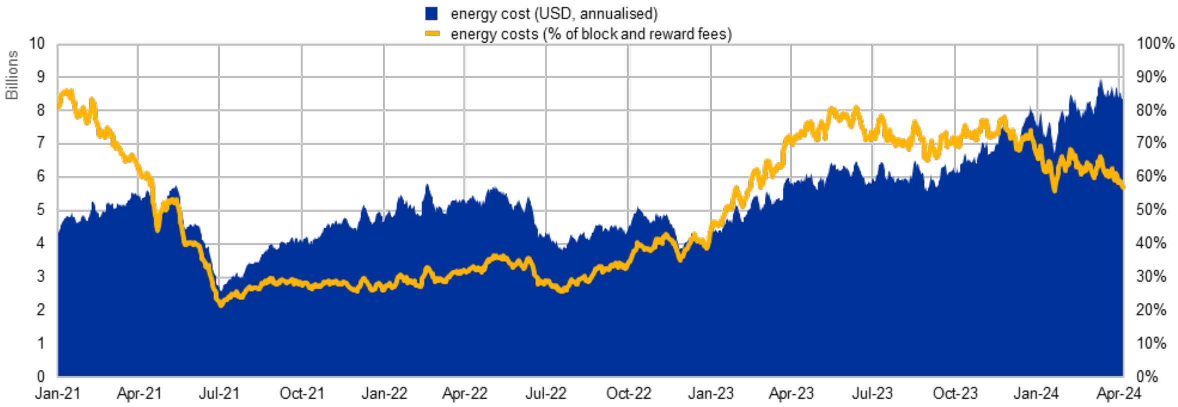
Section 3

Figure 3.1 Cross-country net crypto-asset transaction flow in 2023



Source: Chainalysis and authors' calculations. Notes: DeFi is excluded from the chart.

Figure 3.2 Aggregated energy cost for validation of Bitcoin transactions



Source: Cambridge Centre of Alternative Finance (CCAF) (Cambridge Bitcoin Electricity Consumption Index (CBECI), Chainalysis, CryptoCompare and authors' calculations. Notes: the price of electricity is set to 0.05 USD cents for KWh.

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