Methodologies to calculate sustainability indicators for the EU Markets in Crypto-Assets (MiCA) regulation

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https://carbon-ratings.com

Contents

Introduction and general remarks

The Markets in Crypto-Assets Regulation (MiCA) entered into force in June 2023. Crypto-asset issuers as well as service providers are required to disclose information on the principal adverse impacts on the climate and other environment-related adverse impacts of the consensus mechanism used to issue the respective crypto-asset. The European Securities and Markets Authority (ESMA), which has been mandated to develop draft regulatory technical standards related to sustainability indicators, has proposed ten mandatory climate and other environment-related indicators in their 2nd consultation package which was released on 5th October 2023. The ten indicators cover the areas of energy, GHG emissions, waste production, and natural resources. On 3rd July 2024, ESMA published the final draft technical standard (final draft RTS) related to sustainability indicators in relation to climate and other environment-related adverse impacts. The final draft technical standard specifies one mandatory key indicator on energy and five supplementary key indicators on energy and GHG emissions which are required depending on the entity in scope and the annual energy consumption of the crypto-asset in scope (see orange framed column in Table 1). The indicators on waste production and natural resources which have been proposed as mandatory in the second consultation package are specified as optional indicators in the final draft technical standard alongside a range of other indicators.

Entity in scope	Draft RTS	Revised draft RTS
Person drafting crypto-asset white paper	10 mandatory indicators for all crypto-assets	1 mandatory key indicator and 5 supplementary key indicators for crypto-assets whose consensus mechanism consumes more than 500 000 kWh per year 1 mandatory key indicator for crypto-assets whose consensus mechanism consumes less than 500 000 kWh per year
CASPs providing one or more of the following services: **- Operating a trading platform,** **- Exchanging crypto-assets for funds or** **- Exchanging crypto-assets for other crypto-assets**	10 mandatory indicators for all crypto-assets in relation to which services are provided	1 mandatory key and 5 supplementary key indicators in relation to all crypto-assets whose consensus mechanism consumes more than 500 000 kWh per year, 1 mandatory key indicator in relation to crypto-assets whose consensus mechanism consumes less than 500 000 kWh per year
CASPs only providing services other than those listed above	10 mandatory indicators for all crypto-assets in relation to which services are provided	1 mandatory key indicator for all crypto-assets in relation to which services are provided

Table 1: Overview of approach in final draft RTS (i.e., revised draft RTS) compared to the consultation package (draft RTS).

Objective of this document

This document outlines the methodologies CCRI relies on to derive the six mandatory and supplementary indicators for the MiCA sustainability reporting template as provided in "Annex IV: Draft RTS pursuant to Articles 6(12), 19(11), 51(15) & 66(6) of MiCA" of the " Final Report Draft Technical Standards specifying certain requirements of the Markets in Crypto Assets Regulation (MiCA) – second package", published by ESMA on 3 July 2024, available at https://www.esma.europa.eu/sites/default/files/2024-07/ESMA75-453128700-1229_Final_Report_MiCA_CP2.pdf, p. 178 et seq. ("Draft RTS"). Once official methodology standards become available, CCRI will pursue to ensure timely implementation if changes/updates are required.

In the following, we describe our methodological approaches and provide further background information. If data availability or technical constraints prohibit applying the outlined approach to obtain all relevant input factors, we resort to reference values from a basket of selected peers to obtain the relevant input factors. We will replace and update the proxy input values on an ongoing basis if availability allows. The specific input data and estimates that we use for each crypto-asset to calculate the indicators can be found in the CCRI MiCA API documentation in the sections on Currencies and Sources (for asset-specific inputs/estimates) and MiCA Sustainability Indicators (for inputs/assumptions relevant for all assets).

Methodologies on mandatory and supplementary key sustainability indicators

This section sheds light on the six mandatory and supplementary key sustainability indicators proposed by ESMA.

a. Energy consumption

> "Total amount of energy used for the validation of transactions and the maintenance of the integrity of the distributed ledger of transactions"
> *- ESMA, Final Draft Technical Standards, Annex IV, Table 2, S.8 in Annex*

The final draft RTS defines the total energy consumption of the network (expressed in kWh) as a mandatory indicator. The definitions of the energy consumption required for the validation of transactions and the maintenance of the integrity of the distributed ledger makes the important distinction between transactions and maintenance of the ledger. This is relevant as in later metrics we can discern between the two. For a proper assessment of this indicator, one needs to also consider the impact of transactions on the overall energy consumption in the network.

Proof of Work:

There is a growing body of research on the energy consumption of a Proof of Work (PoW) blockchain network, and two main approaches can be distinguished: a) Top-down and b) Bottom-up. We briefly describe both, but rely on the bottom-up approach, as we consider it more accurate and later metrics also profit from an implementation of a bottom-up approach.

- **The top-down approach** was populated by Alex de Vries' Digiconomist Bitcoin Energy Consumption Index.[1] It assumes that the money earned by miners is directly invested, to a certain degree, into energy. With data available on the miner's earnings (consisting of block subsidy and transaction fees), the exchange rate for bitcoin, and the assumption that a predefined share of earnings is spent on energy, it is straightforward to calculate the respective monetary value of energy. With an assumption on the last variable, the average electricity price, one is able to calculate the total network energy consumption on a daily basis.

- **The bottom-up approach** was initially developed in (Krause & Tolaymat, 2018)[2], refined in (Stoll, Klaaßen, Gallersdörfer, 2019)[3] and is now also used in the Bitcoin Energy Consumption Index by CCAF.[4] Instead of directly looking at miners' earnings, the bottom-up approach considers the hash rate to be the main (direct) driver of the energy consumption of the network and focuses on it. In PoW, the devices in the network need to solve a hash puzzle, thus requiring a lot of energy. A bottom-up approach requires a list of available hardware devices and their

[1] https://digiconomist.net/bitcoin-energy-consumption.
[2] Krause, Max J., and Thabet Tolaymat. "Quantification of energy and carbon costs for mining cryptocurrencies." Nature Sustainability 1.11 (2018): 711-718.
[3] Stoll, Christian, Lena Klaaßen, and Ulrich Gallersdörfer. "The carbon footprint of bitcoin." Joule 3.7 (2019): 1647-1661.
[4] https://ccaf.io/cbnsi/cbeci

power demand and hash rate. By taking the average electricity price, one is able to generate a list of profitable devices at any given time in the network, utilizing the current hash rate of the network. The profitable devices can be weighted according to their age and availability in the market, thus creating a list of devices that run at any given point in time, allowing to calculate the daily power demand (and thus the total annualized energy consumption of the network).

To derive the energy consumption of Proof-of-Work networks, we use the following steps:

1. We determine the hashrate of the network by observing the block times and the difficulty target.
2. We determine the proof-of-work algorithm and depending on the algorithm, we identify mining devices for the respective algorithm. If ASIC-devices are broadly available for an algorithm, we rely on the hardware list provided by ASICMinerValue.com.[5]
3. We determine the profitable hardware devices by accounting for the current mining reward and the electricity price.[6]
4. We determine a weighted basket of profitable hardware devices similar to the principles of the approach used by the Cambridge Bitcoin Electricity Consumption Index. The weight of a specific hardware device depends on its estimated deployment date.[7] The weight factor assigned depends on the time that has passed since the release date of the hardware device. We assume that a profitable device remains present in the portfolio for no more than five years after its deployment. In the first year, the device is assigned a weight of 1. This weight decreases over time, dropping to 0.8 in the second year, 0.6 in the third year, and so on, until it reaches 0 after five years.
5. Based on the weighted basket of profitable hardware and the electricity rate combined with the total hashrate of the network, we may derive the energy consumption.

Proof of Stake / Proof of Authority:

For networks that do not rely on a Proof of Work or other computationally heavy algorithms (e.g., Proof of Stake, or Proof of Authority), a uniform approach can be applied to generate the total energy consumption. The driver of the total energy consumption in such networks is the node devices in the network, both their count as well as their individual power demand.

"Number of nodes" is a metric that is often readily available. Block explorers or other data providers are able to analyze the P2P network and understand how many entities are connected to the network and provide (depending on the specific algorithm) computational and storage capacity. We include both full nodes and validating nodes, as the final draft RTS specified that an assessment should include "*the maintenance of the integrity of a distributed ledger of transactions by all DLT network nodes*".[8]

In contrast to the number of nodes, the power demand of the individual devices is not available. Some research papers estimate the power demand per node based on common hardware requirements of the network. However, such an approach does not allow for nuanced differentiations between different networks, as it is not possible to deviate average power demands from basic performance metrics of the network, such as transaction throughput. This can be addressed through generating the data by setting up nodes and measuring the energy consumption in real-world scenarios. CCRI has developed a

[5] For Ethereum pre-Merge (i.e., before September 2022) we use a more stylized approach relying on a hardware list of whattomine.com, but without determining profitable hardware devices. In this stylized models all available hardware devices are included. This is irrelevant for all sustainability indicators under MiCA which are only reported going foward and do not include time frames prior of Ethereum's Merge.
[6] We assume a constant and average electricity price of 0.05 $/kWh for all PoW-based networks. This is in alignment with the Cambridge Bitcoin Electricity Consumption Index which assumes a constant electricity price of 0.05 $/kWh for Bitcoin (an SHA-256-based algorithm).
[7] The estimated deployment date is assumed to be 2 months after the release date as devices need to be delivered first.
[8] ESMA Final Draft RTS, 8.4, Annex IV (7), p. 179

reference hardware set that includes low-tier nodes such as a Raspberry Pi up to server-grade hardware. With this hardware set, CCRI generates data for an average node of each of these blockchain networks. The individual power demand is enhanced with a marginal energy consumption per transaction that is calculated based on the power demand and transaction throughput of the node during a measurement period. A detailed description of the methodology to conduct the measurements which is applied by CCRI is available here.

Tokens

To calculate the total energy consumption of a token that exists on a blockchain, one needs to first understand the energy consumption of the underlying network (see previous section). Once this data is readily available, one can allocate the total energy consumption to an individual token by allocating the energy consumption from the base chain for which the token is responsible for the individual token. CCRI uses the hybrid allocation framework[9] developed together with South Pole and under the consultation of PayPal to allocate the share of energy that holdings and transactions from a specific token trigger on the base layer. If a token is live on multiple base chains, we derive the share of energy consumption that needs to be allocated to the token for the most relevant base chains and aggregate it to the total energy consumption.[10] A detailed description of the hybrid allocation approach can be found in the description of indicator *Energy intensity*.

Layer 2 networks

Layer 2 networks employ their own consensus mechanisms in addition to being responsible for the activity on the base chain that provides additional security guarantees. For determining the energy consumption of layer 2 networks, we combine the PoS approach (for the own network) with the token approach (for the base layer network) and add them up for total energy consumption.

b. Renewable energy consumption

> "Share of energy used generated from renewable sources, expressed as a percentage of the total amount of energy used per calendar year, for the validation of transactions and the maintenance of the integrity of the distributed ledger of transactions"
> *- ESMA, Final Draft Technical Standards, Annex IV, Table 3, S.10 in Annex*

The calculation of the share of renewable energy consumption is not dependent on the type of blockchain or consensus mechanism. Therefore, the same approach fits all different blockchain consensus mechanisms.

The central data point required for the calculation of the indicator *Renewable energy consumption* is the location of the respective entities that consume energy as well as their share in the network. Determining location information is dependent on the network type (and is required for other indicators as well), so

[9] https://carbon-ratings.com/accounting-framework-2022

[10] As some tokens live on a large multitude of chains of which most only contribute to very little extent to the energy consumption, we focus on the most relevant chains and extend the coverage of base layers on an ongoing basis. The base layers that are currently covered for the respective token can be found in the CCRI MiCA API documentation in the section on Currencies and Sources (for asset-specific inputs).

we provide an overview of the methodologies to generate location information by network type and outline CCRI's approach:

- **PoW networks:** It is not trivial to generate location information for PoW networks, given their secretive nature. Energy consumption and price are core to the business of any miner and therefore sharing any information might benefit competitors. Therefore, miners often do not proactively share their location, and also obtaining other data that can be used for triangulation (e.g., IP addresses) is difficult, as blocks are propagated through mining pools, so directly connecting and observing miners is rarely possible. Some pools periodically publish aggregated data[11], and Cambridge University publishes its joint work with mining pools in their Bitcoin mining map which however could not be updated since January 2022.[12] Against this backdrop, CCRI collects location information from official filings of publicly listed crypto-assets mining companies. This approach has only recently become viable as more mining companies have gone public, disclosing quarterly filings that include critical information about their data centers—most notably operational hashrate, power consumption, and geographic location. As of the Q3 2024 filings, we have been able to identify mining locations for over 35% of the Bitcoin total hashrate by analyzing the largest publicly listed mining companies.[13] This coverage is comparable to the share of the Bitcoin network analyzed by Cambridge University between October 2019 and January 2022, which ranged from 32% to 38% depending on the specific period.[14] We acknowledge that a significant portion of the network remains unanalyzed due to the lack of public filings, requiring reliance on global averages for the share of renewable energy for this portion of the network. Nonetheless, the primary advantage of using quarterly filings from publicly listed companies lies in the timeliness of the data, which we update regularly as new filings become available. Furthermore, we anticipate that the share of the network covered by publicly listed miners will increase as the industry continues to mature. Data for other PoW networks are more difficult to obtain, but as they follow very similar incentive structures as Bitcoin and are often mined by the same mining companies, we use Bitcoin's location data as a proxy for them.
- **Other networks:** For other networks, including Proof of Stake, Proof of Authority, or Byzantine-style consensus mechanisms, location data is often easier to obtain than in PoW networks. Block explorers, specific companies working on identifying locations[15], or other data sources are readily available to be used for geo-footprinting. CCRI uses external data providers to gather location data of the nodes in the network. If the location information of a certain share of nodes in unavailable, we use the world average for this share. If for a network location information is not available, a world average is used.

By combining the location information with regional and country-level data on the share of renewable energy in the grid, which we obtain from external data sources, we may calculate the share of renewable energy used for the entire network. In this context, it is important to note that ideally one would know the share of renewables used by each entity directly as well as how the claim of potential use of renewable energy is backed up (e.g., through renewable energy certificates). As of today, this information is very different to collect for all types of networks which is why we rely on location information and regional and country-level information on the share of renewable energy within a grid.

[11] E.g., Foundry: https://medium.com/foundry-digital/foundry-usa-pool-hashrate-by-state-f9dc92e7bc3b
[12] https://ccaf.io/cbnsi/cbeci/mining_map.
[13] To maximize the share of hashrate captured, we include data from both self-hosted mining capacities and externally hosted capacities. However, we aim to exclude mining capacities that rely on hosting agreements between two parties when both parties are within our analysis sample and the agreement parties are explicitly stated, to prevent double counting.
[14] https://ccaf.io/cbnsi/cbeci/mining_map/methodology
[15] For example, MigaLabs provides a detailed overview of full nodes in the Ethereum network. See https://monitoreth.io/nodes.

c. Energy intensity

> "Average amount of energy used per validated transaction" – expressed in kWh
> - *ESMA, Final Draft Technical Standards, Annex IV, Table 3, S.11 in Annex*

The final draft RTS differentiates between the energy consumption for securing the integrity of the ledger and the energy consumption for validating transactions, as seen in the indicator *Energy consumption*. This distinction is important, as it highlights the need for a methodology to assess the energy consumption of a single transaction not merely by dividing the total consumption by the number of transactions, as this would indicate that the entire energy consumption is attributable to transactions.

For energy allocation, we define two types of activities in blockchain networks, namely transactions (either in the form of transaction count, transaction fees or gas consumption) and holdings (either in the form of the base unit or its monetary value in USD). Overall, there are three ways to allocate energy consumption to these activities:

- **Holding-based approach**: The holding-based approach mandates us to calculate the energy consumption per held unit. Therefore, we divide the total energy consumption of the network by the total supply of the network, resulting in a value of energy consumption per unit. The timeframe is defined by the timeframe of the energy consumption, e.g., a day or a year. This approach does not consider transactions to be a driver of energy consumption. Holding currencies can, especially in the case of PoW networks, be the main driver of energy consumption: Holders are the entities that pay the mining reward in PoW networks, as the inflation of the currency is paid as a reward to the miners and impact all holders of the currency equally. That indirect payment allows the miners to continue their business and spend their rewards (partially) on energy. The holding-based approach can be used in times of low or no transaction fees for miners and highlights the importance and cost of securing the ledger in contrast to the execution of transactions.

- **Transaction-based approach**: The transaction-based approach follows the simple approach, as previously described, to divide the total energy consumption by the number of transactions that occurred during the same period of time. While this metric is easy to calculate, it is often misleading, as calculating this metric does not consider the nuances of the network, e.g., as Proof of Work does not only secure the execution of the current transactions but also protects the integrity of the "non-moving" coins. Other networks that provide file storage would also need to distribute storage-related energy use to transactions without any logical connection whatsoever.

- **Hybrid approach**: The hybrid approach is a methodology developed by South Pole together with CCRI and under the consultation of PayPal[16] and has been further developed since then to cater to new developments and insights in the crypto market, such as layer 2 networks or further consensus mechanisms.[17] The basic idea is to distribute the total energy consumption between all activities in the network, both holdings and transactions. The respective shares can then be divided by the total amounts of the activities (such as total supply or transaction throughput), resulting in and creating individual metrics for each of the activities.

[16] https://carbon-ratings.com/accounting-framework-2022.
[17] https://arxiv.org/abs/2111.06477.

We use the hybrid approach, as a) it is in line with the MiCA regulation and b) provides fair and comparable metrics between different cryptocurrencies. The core of the hybrid approach is the split-up of the total energy consumption, and there are, depending on the Consensus Mechanism, different ways to define these shares, depending on the drivers of energy consumption.

- In **PoW networks**, the main driver of energy consumption is the monetary incentive of the miner. Miners receive transaction fees and a block subsidy. From a logical point of view, we are able to allocate transaction fees to entities that transact, and block subsidy to the entities that hold. Entities that hold do provide an incentive to the miners, as their monetary holdings get devalued due to inflation by creating new coins. Therefore, the share between transaction fees and block subsidy can be used as a driver for the hybrid allocation.
- In **PoS networks**, transaction fees do not incentivize the validators to spend money on energy. Instead, transactions are rather a small part of the total energy consumption of the nodes, as the regular maintenance of the ledger consumes energy regardless of the transaction throughput. Therefore, we use the marginal energy consumption per transaction, which we calculated for indicator *Energy consumption*, as a driver to discern between transactions and holdings, attributing the marginal energy consumption to transactions and the remainder to the holders.

d. Scope 1 DLT GHG emissions – Controlled

To derive the GHG emissions for the validation of transactions and the maintenance of the integrity of the distributed ledger of transactions, two components are required: (1) the energy consumption and (2) the emission intensity of the energy consumed. The first component has been derived in a previous subsection and now serves as a direct input for this indicator. The second component needs to be collected in accordance with established carbon accounting methods.

> "Scope 1 GHG emissions per calendar year for the validation of transactions and the maintenance of the integrity of the distributed ledger of transactions" - expressed in tonnes (t) carbon dioxide equivalent (CO2e)
>
> - *ESMA, Final Draft Technical Standards, Annex IV, Table 3, S.12 in Annex*

The final draft RTS defines this indicator as scope 1 GHG emissions for the validation of transactions and the maintenance of the integrity of the distributed ledger of transactions. The distinction between the validation of transactions and the maintenance of the integrity of the distributed ledger of transactions is analogous to the previous section on energy. However, special attention needs to be paid to the different scopes of the emissions.

The distinction of the emission in different scopes has been introduced by the GHG Protocol which provides guides for carbon accounting at the corporate level.[18] Scope 1 is defined as direct GHG emissions from sources that are owned or controlled by the company. As a crypto-asset is not a company, the distinction in emission scopes may seem somehow misleading in this context. The final draft RTS defines *Scope 1 DLT GHG emissions* as "GHG emission generated from sources that are controlled by the DLT network nodes applying the consensus mechanism". We argue that a reasonable interpretation of this specification is to think of this as the GHG emissions that are owned or controlled by the ones who validate transactions and maintain the integrity of the distributed ledger transactions (i.e., miners/

[18] https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf.

node operators). As the GHG emissions for the validation of transactions and the maintenance of the integrity of the distributed ledger occur during the production of the energy that is consumed, the GHG emissions would only be owned or controlled by the miners or node operators in case they are producing the energy themselves. Large mining companies that need vast amounts of energy could run their own power plants. However, it is extremely challenging to determine the GHG emissions associated with mining operations that are (partly) fueled by such power plants that are owned or controlled by the mining company given that those are often run by a combination of owned or controlled plants and a grid connection to ensure ongoing operations. This is why we assume that miners and node operators are purchasing the energy they use (which represents scope 2 – see indicator *Scope 2 DLT GHG emissions - Purchased*) given the difficulties of distinguishing between scope 1 and scope 2 emissions from an outside-in perspective. As soon as disclosure of mining companies regarding the distinct scope 1 and scope 2 emissions becomes available, CCRI pursues to reflect this in the MiCA sustainability indicators.

e. Scope 2 DLT GHG emissions - Purchased

> "Scope 2 GHG emissions, expressed in tCO2e per calendar year for the validation of transactions and the maintenance of the integrity of the distributed ledger of transactions"
>
> *- ESMA, Final Draft Technical Standards, Annex IV, Table 3, S.13 in Annex*

The final draft RTS defines this indicator as scope 2 GHG emissions for the validation of transactions and the maintenance of the integrity of the distributed ledger of transactions. Also in this case, the distinction between the validation of transactions and the maintenance of the integrity of the distributed ledger of transactions is analogous to the previous section on energy. In the GHG Protocol, Scope 2 is defined as indirect GHG emissions from emissions from the generation of acquired and consumed electricity.[19] The final draft RTS defines *Scope 2 DLT GHG emissions* as "GHG emissions from the consumption of purchased electricity, steam, or other sources of energy generated upstream from the DLT network nodes applying the consensus mechanism". We argue that the majority of the miners and node operators purchase the electricity they consume rather than producing it themselves, resulting in higher scope 2 emissions compared to scope 1 emissions for most crypto-assets. The GHG Protocol presents two complementary methods to report scope 2 emissions:

- **Location-based method:** It reflects the average emissions intensity of grids on which energy consumption occurs (usually applying grid-average emission factors). Therefore, the method requires the amount of energy consumed at each location (see indicator *Renewable Energy Consumption* for an overview for the collection of location data) as well as the respective grid-average emission factors which are often published by state authorities (e.g., by the United States Environmental Protection Agency for U.S. states).

- **Market-based method:** It reflects emissions from the energy that companies have purposefully chosen (or their lack of choice). It derives emission factors from contractual instruments, which include any type of contract between two parties for the sale and purchase of energy bundled with attributes about the energy generation, or for unbundled attribute claims. As such, the market-based method does not only require information on the contractual

[19] https://ghgprotocol.org/sites/default/files/2023-03/Scope%202%20Guidance.pdf.

instrument used (as well as associated credible claims) but also emission factors representing the untracked or unclaimed energy and emissions (termed the "residual mix") for the share of electricity for which there is no contractual information that meets the Scope 2 Quality Criteria.

The final draft RTS specifies that "Where DLT network nodes use mechanisms to off-set their energy consumption and GHG emissions, the use of these mechanisms may be separately disclosed in the section 'Sources and methodologies' of Tables 2, 3 and 4 of the Annex. The effect of such offsetting mechanisms shall not be taken into account when calculating the climate and other environment-related indicators." This is in line with the GHG Protocol which also requires to disclose the metrics of both methods separately if one decides to start calculating scope 2 emissions with the market-based method (this is termed "dual reporting"). As the market-based method was introduced as a complementation to the location-based method, we are solely using the location-based method for the key indicators in line with the guidance from the final draft RTS.

f. GHG intensity

> "Average GHG emissions (scope 1 and scope 2) per validated transaction" - , expressed in kilogram (kg) CO2e per transaction (Tx)
>
> *- ESMA, Final Draft Technical Standards, Annex IV, Table 3, S.14 in Annex*

The final draft RTS defines this indicator as the average GHG emissions (scope 1 and scope 2) per validated transaction. This metric can be derived in the same way as described for the average energy consumption per validated transaction required for the indicator *Energy intensity*.

Methodologies on selected optional sustainability indicators

The following indicators have been proposed as mandatory in the Consultation Package but have been specified as optional in the final draft RTS.

g. Generation of waste electrical and electronic equipment (WEEE)

> "Total amount of WEEE generated for the validation of transactions and the maintenance of the integrity of the distributed ledger of transactions per calendar year" - expressed in tonnes
> - *ESMA, Final Draft Technical Standards, Annex IV, Table 4, S.22 in Annex*

The final draft RTS defines this indicator as the total generation of waste electrical and electronic equipment. The generation of electronic waste is dependent on the hardware usage of the network and how fast devices are replaced – either because of hardware depreciation, performance issues, or implications on the revenue. Depending on the specifics of the hardware replacement, we calculate the total electronic waste in two consecutive steps:

1. **Understand the hardware composition and weight of devices**: The indicator *Energy consumption* calculates the total energy consumption of the respective network; to do so, we made assumptions on the hardware composition, both on device type and distribution between devices. This hardware composition, whether in PoW with the number of ASIC devices or in PoS with the number of node operating devices, provides the basis for the calculation of the number of total devices in the network. In the next step, we collect hardware weights for all devices present in the previously derived device distribution.

2. **Define the depreciation time frame**: Once we know the hardware composition for a given day in the network, we calculate the WEEE generated on that day with a given depreciation time frame.[20] For PoW-based networks, we assume a depreciation timeframe of 5 years. For PoS-based network, we use a depreciation time frame of 3 years.[21]

[20] Example: If a hardware device is deprecated over 5 years, then the generated WEEE of devices is calculated by the devices' weight divided by the total days the devices are in use (5 years = 1,825 days).
[21] The Cambridge Bitcoin Electricity Consumption Index assumes a lifetime of 5 years for PoW. Operators of data centers usually replace their hardware once service levels are no longer valid, which is, in case of enterprise hardware, often after 3 years. Anecdotal evidence from interviews with node operators within various networks suggests replacement rates between 2 years and +5 years.

h. Non-recycled WEEE ratio

> "Share of the total amount of WEEE generated for the validation of transactions and the maintenance of the integrity of the distributed ledger of transactions, not recycled per calendar year, expressed as a percentage."
> *- ESMA, Final Draft Technical Standards, Annex IV, Table 4, S.23 in Annex*

The final draft RTS defines this indicator as the share of non-recycled WEEE. To calculate this metric, one needs to consider the location of miners and node operators (see indicator *Renewable energy consumption* for an overview) as well as the local recycling rates for WEEE at the respective locations. Similarly, to energy sources and emission factors of a country or region, we obtain local recycling rates from external sources.

i. Generation of hazardous waste

> "Total amount of hazardous waste generated for the validation of transactions and the maintenance of the integrity of the distributed ledger of transactions, per calendar year" - expressed in tonnes
> *- ESMA, Final Draft Technical Standards, Annex IV, Table 4, S.24 in Annex*

The final draft RTS defines this indicator as hazardous waste generated by the network. As we calculated the waste component of the network already in the indicator *Generation of waste electrical and electronic equipment (WEEE)*, we are able to build upon that figure and calculate the hazardous waste as a share of the total electronic waste and provide a respective value expressed in tonnes per calendar year.

Hazardous waste is a term that is linked to European Union Guidelines "Waste Electrical and Electronic Equipment Directive (WEEE Directive)" (2012/19/EU) and Restriction of Hazardous Substances Directive (2011/65/EU, RoHS 2) which properly defines contents of electronic devices as hazardous substances, such as lead, mercury, cadmium, and others.

We rely on the hardware composition described in the indicator *Generation of waste electrical and electronic equipment (WEEE)* and "Restriction of Hazardous Substances Directive Report" (RoHS Report), which needs to be published by respective vendors.[22] We aggregate the weight of hazardous materials described in these documents for each device. Combining the weight of hazardous waste per device with the information on hardware device distribution and depreciation time frames, we derive the total hazardous waste generated by the network. If the ROHS Report is not available for all types of devices in the network, we rely on reports from similar device types for which the report is available as a proxy.

[22] For example, Intel produces such reports, e.g., for Intel NUCs: https://cdrdv2-public.intel.com/728760/xnuc11atkc4000x%20%20Declaration%20Form%20Build%20-%2068241.pdf.

j. Impact of the use of equipment on natural resources

While the final draft RTS asks for very concrete metrics for the other indicators by defining exact time periods and units, this indicator is more generally defined.

> "Description of the impact on natural resources of the production, the use and the disposal of the devices of the DLT network nodes"
> *- ESMA, Final Draft Technical Standards, Annex IV, Table 4, S.29 in Annex*

The final draft RTS defines this indicator as a description of the general impact of the devices of DLT network nodes on natural resources, such as water, fossil fuels, and critical raw materials during the production, use, and disposal phase. Particularly, water consumption during the use phase has already been discussed in the context of Bitcoin.[23] Water consumption is heavily driven by the amount of energy consumed by the network as well as the regional water intensity of the electricity consumption. We focus on the water consumption during the use case as a quantitative metric alongside the general description of the impact. To do so, the energy consumption, the location of node operators as well as regional electricity water footprint is used as an input to assess the water consumption of a crypto-asset during the use phase.

[23] de Vries, Alex. "Bitcoin's growing water footprint." Cell Reports Sustainability 1.1 (2024).