JUL 2024

Network Assessment & Methodology

Cardano

Sustainability Indicators of the Cardano Network

EXECUTIVE SUMMARY

Network Assessment

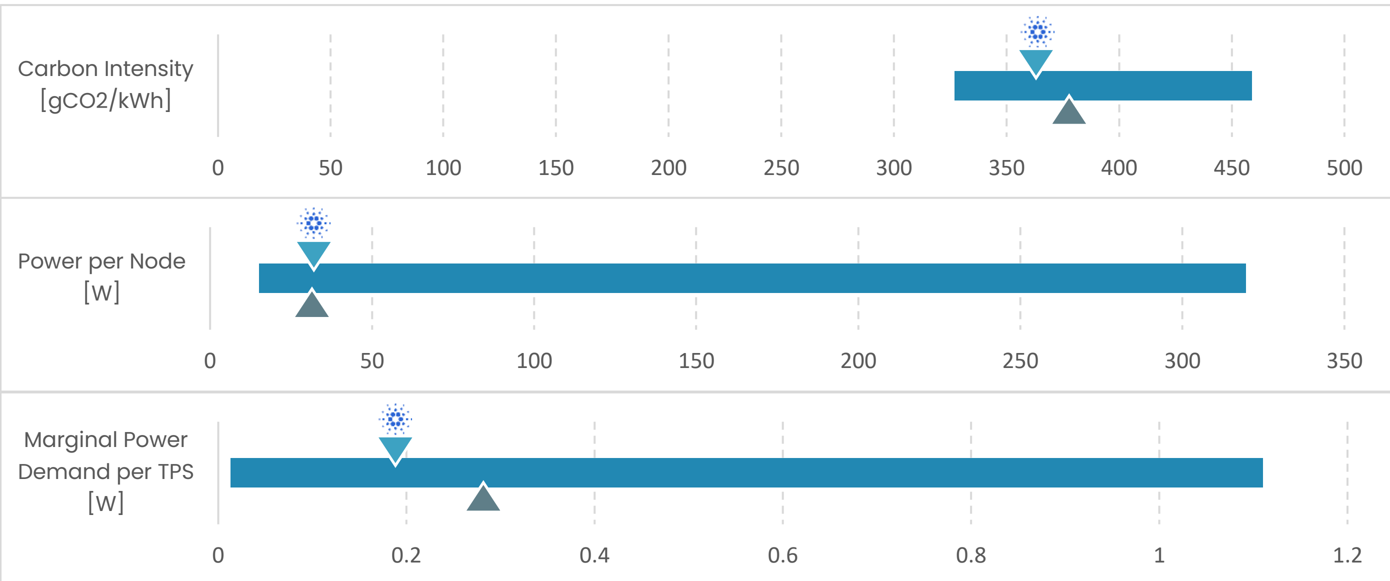
Cardano

July 2024

The analyses underlying this report were commissioned by the Cardano Foundation.

- Cardano employs an **energy-efficient consensus protocol**. In comparison to Proof of Work (PoW)-based protocols such as Bitcoin, Cardano **consumes significantly less electricity.**
- We find a **total annualized electricity consumption** of 704.91 MWh for the Cardano network, as of May 2024.
- Furthermore, we calculated the **carbon emissions** associated with the annual electricity consumption via location-specific **emission factors,** taking into account the locations of the **validator nodes**.
- For the Cardano network, we find a **total annualized carbon footprint of 250.73 tCO_2e.** The carbon intensity of the consumed electricity sits at **356 gCO_2 per kWh**.
- The **marginal power demand** per TPS (transactions per second) in the Cardano network amounts to **0.192 W**.
- In addition to electricity consumption and carbon footprint, **we provide sustainability metrics** in line with the draft regulatory technical standards (RTS) provided by the European Securities and Markets Authority (ESMA) in the second consultation package of the **Markets in Crypto-Asset (MiCA)** regulation.

SELECTED BENCHMARKING RESULTS



Legend: indicates the range, Cardano's performance and median value of the peer group*.

*Peer group consists of the networks that were assessed in the latest CCRI PoS Benchmarking Study. Available here: https://carbon-ratings.com.

A. NETWORK ASSESSMENT METHODOLOGY

1 PREAMBLE

CCRI **follows a standardized assessment process for Proof of Stake networks** (CCRI, 2022)[1], making reasonable assumptions if specific knowledge is not available outside in as described in the standard methodology. In this assessment of the Cardano network, CCRI is able to access details about network specifics provided by the Cardano Foundation, allowing an adjustment of the methodology and key metrics. For transparency, any deviations from the standardized approach in (CCRI, 2022)[1] are highlighted in blue.

2 STRUCUTRE OF THE MODEL

The model generates several key sustainability metrics of the Proof of Stake network, namely **electricity consumption** and **carbon footprint of the network**. For this, the model considers the nodes in the network and their individual power demands under different transaction throughput rates. The model contains following steps:

1. **We calculate the power of the entire network** (P_N), which we obtain by multiplying the number of nodes in the Cardano network (NC) by the power consumption of a representative node in the network (P_{BG}). To determine the power demand of the single best guess node, we leverage the measured metrics: we multiply the transactions per second (TPS) with the marginal power demand per one TPS (P_m), and add the node's base power demand (P_b), i.e., the power demand if the Cardano node software is executed at zero transaction throughput, to it:

$$P_N = P_{BG} * NC$$

$$P_{BG} = P_b + P_m * TPS$$

2. We derive the **electricity consumption of the Cardano network** (E_N) over a specific time period by multiplying the network's total power demand (P_N) by the considered time ($t[h]$):

$$E_N = P_N * t[h]$$

3. Third, we **calculate the carbon footprint of the Cardano network** (CF_N) by multiplying the network's electricity consumption over the regarding time period (E_N) by the carbon intensity factor of the network's grid (CI):

$$CF_N = E_N * CI$$

3 NETWORK ASSESSMENT

To generate the required parameters (namely P_b, P_m, CI, and NC), we follow the process as described in (CCRI, 2022)[1]. This standard methodology builds upon five steps to generate data on the electricity consumption and carbon footprint of a PoS system.

3.1 HARDWARE SELECTION

To come up with a representative hardware set of the network, we investigate Cardano's minimum hardware requirements, as these are an indicator of the hardware composition of the network. We use this information and additional hardware data from PassMark to select and obtain hardware that we use to measure a single node's electricity consumption. For measuring the Cardano network, we select devices 4-6 from our hardware (see Appendix for the devices' specifications).

Generally, it is difficult to obtain the individual hardware composition of a network from an outside perspective. Therefore, we usually rely on a binomial distribution, assuming that entities always adhere at least to the minimum hardware requirements, but also might run hardware that is more potent. For Cardano, we were able to access a recent survey of Stake Pool Operators (SPOs) that allows us to deviate from a binomial distribution and rather seek a more representative distribution, as highlighted in the Appendix ("Hardware specific measurement result" -> "Assumed node distribution").

3.2 HARDWARE MEASUREMENT

We measure the electricity consumption of a single node and provide upper and lower bounds for nodes in the Cardano network. We start by running the software required for participating in the network (cardano-node v8.9.2) on all selected hardware devices and measure their electricity consumption while running the network and while idling. To be able to evaluate additional metrics, we capture further data points during the execution, such as CPU utilization, temperature, and processed blocks.

When measuring the nodes, our measurement system periodically retrieves the average power demand over the last 30 seconds. To match the block time of Cardano, we set this variable to 20 seconds.

3.3 ELECTRICITY CONSUMPTION

We estimate the electricity consumption of the entire Cardano network. First, we collect information about the size of the network, i.e. the number of active SPOs and potential relay nodes, as the node count significantly influences the total amount of electricity consumed. Second, we use the **weighting mentioned in 3.1** between the single measured hardware devices to best fit the composition of the Cardano network. Third, we multiply the electricity consumption of the weighted nodes by the number of nodes in the network.

The number of nodes in the network is crucial for a proper assessment. CCRI analyzed the activity of SPOs and their block production rate, including their expected block production rate. We observed that not all SPOs that have an active stake (eligible to produce blocks) participate in the network, as they produce zero blocks (while expected to produce a sufficient number of blocks), meaning that they are offline. Given that there are no slashing or other mechanisms to

[1] CCRI (2022). Determining the electricity consumption and carbon footprint of Proof-of-Stake networks. https://carbon-ratings.com/dl/whitepaper-pos-methods-2022

discourage such behavior (except opportunity costs), we do not consider such SPOs actively participating in the network and thus do not include them in the overall calculation of the electricity consumption (resp. the carbon footprint) of the network. Instead, we consider the active producing SPOs for our model.

The number of devices per SPO is also a key variable in the model. In this assessment, we assume that one SPO operates three devices on different machines, namely one block producer and two relays. This decision is based on following observations within the network:

- *SPO questionnaire*: The questionnaire shared by Cardano Foundation included a question on how much relays a SPO uses for its block producing node, whereas the mean number of relays was 2.03 (n=239), resulting in a total of three devices.
- *Network data observation*: The data generated by Cardano's blockperf[2] allows an observation of how much relays a block producer is using. Over the last epochs (475 – 483) the mean number of relays ranged from 1.97 to 2.15 nodes, confirming our assumption.
- *Best practice*: If no other data is available, we usually rely on an official node setup description, that highlights how much devices the node operator should deploy. Cardano has a guideline for operating large stake pools, which explicitly mentions the three-device setup "it is recommended that an SPO maintains at least two and an additional relay node(s) per a stake pool."[3]

3.4 PERFORMANCE METRICS

We analyze additional data, such as transaction and block information, to develop further metrics to explore the energy efficiency of transaction throughput for each network. We take samples of the nodes' electricity consumption periodically and examine the number of transactions that the single nodes handled during the respective time periods. This allows us to describe the marginal influence of the number of transactions on the electricity consumption of a node in the Cardano network. As a result, we establish a model to estimate a best guess node's power demand based on the number of transactions. This enables us to model the electricity consumption of the Cardano network over time, as node count and transaction volume change.

3.5 CARBON FOOTPRINT

We estimate the CO_2 emissions arising from the operation of the Cardano network. To do so, we use our data on network electricity consumption and multiply it by the carbon intensity of the network. We derive an appropriate carbon intensity of the network by leveraging the respective grid emission factors of the regions where the SPOs are located.

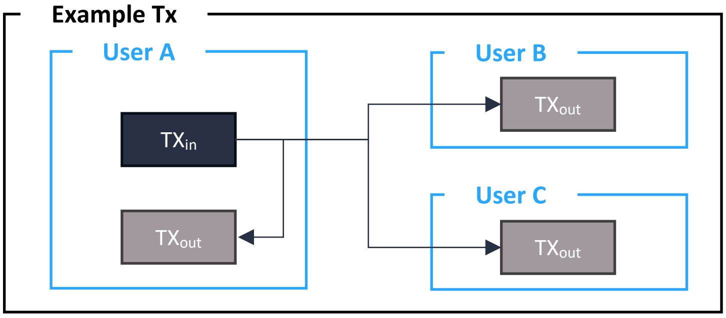
We use location data that is generated by Cardano's blockperf[2] monitoring tool. The tool allows us to observe the location of the block producing SPOs.

[2] Cardano blockperf, https://github.com/cardano-foundation/blockperf

[3] See https://docs.cardano.org/operating-a-stake-pool/guidelines-for-large-spos/#provisioning

4 ADDITIONAL TRANSACTION-BASED LEDGER METRIC

Cardano employs a transaction-based ledger (in contrast to an account-based ledger in most other PoS networks). It therefore relies on unspent transaction outputs (UTXO)[4], that contain the funds of the respective address. If users want to spend the funds associated with an UTXO, they need to provide a new transaction with a transaction input (TX_{in}), that refers to the respective UTXO. The transaction itself creates new UTXOs that allow for further spending. The signature of the transaction is contained within the TX_{in}. Below you see an example transaction in which *User A* sends *User B* and *User C* funds in one transaction.



Example transaction in a transaction-based ledger

The TX_{out} sent back by User A to itself is required, as UTXOs cannot be spent partially. Therefore, the remaining funds of a UTXO need to be sent to a new UTXO, belonging to the same user. This UTXO is referred to as a *change address*.

The transaction-based ledger allows a single user to execute multiple payments in a single transaction, leading to a higher efficiency compared to creating a transaction for each user individually. Theoretically, this is also possible for account-based ledgers, but comes with downsides[5].

Therefore, we introduce a new metric for transaction-based Proof of Stake networks called **marginal power demand per UTXO per second**. For the time period of our measurement, we additionally gather UTXOs (excluding change addresses) and calculate the marginal power demand per UTXO per second metric. The table below summarizes the results of our assessment.

Marginal Power Demand per UTXO per second [W]	0.106
24h-analysis-period transaction count [#]	53,507
TX_{out} (excluding change addresses) [#]	89,014
Average TX_{out} per Transaction [#]	1.66
Observed Block Range [#]	10,227,951 – 10,232,272

Transaction-based ledger metrics

This metric provides an interesting perspective on the inner workings of transaction-based ledgers and its efficiencies. For the results, updated results published in CCRI's API, and the proposed sustainability indicators under MiCA, we adhere to the standard definition of a transaction.

[4] UTXO refers to an **unspent** transaction output. We refer to transaction outputs irrespective of their spending as TX_{out}.
[5] In an account-based ledger, smart contracts and messages can be leveraged to execute multiple payments within one transaction but are associated with additional costs and setup efforts.

B. RESULTS

Cardano: Electricity Consumption and Carbon Footprint
(all metrics as of April 25, 2024)

KEY NETWORK METRICS

Name	Cardano
Symbol	ADA
Consensus mechanism	PoS (Ouroboros)
Network type	Layer 1
Node count	3,147 (1,049 SPOs with three devices each)
24h-analysis-period transaction count	53,507
Annualized transaction count	19,530,055

KEY FINANCIAL METRICS

Market Capitalization (Rank) [USD]	16,784,282,077.33 (#10, CoinMarketCap)
Market Price [USD]	0.471
Circulating Supply [ADA]	35.633.902.492
24 hours Trading Volume [USD]	348,258,880.11

KEY ELECTRICITY METRICS

Average electrical power per node [W]	25.57[6]
Electrical power of network [KW]	80.47
Annualized electricity consumption [MWh]	704.91
Marginal power consumption per TPS [W]	0.191975

KEY CARBON METRICS

Annualized CO_2 emissions [t]	250.73
Marginal CO_2 emissions per tx [g]	0.000018987
Applied CO_2 emission intensity [kg/kWh]	0.356

[6] Value for a representative node assuming the node distribution among hardware configurations as shown in the Appendix.

C. METHODOLOGY FOR SUSTAINABILITY INDICATORS UNDER MICA

1 PREAMBLE

The Markets in Crypto-Assets (MiCA) Regulation 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 standards related to sustainability disclosure, 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.

Art 6 (1): Content and form of the crypto-asset white paper:

(j) information on the principal adverse impacts on the climate and other environment-related adverse impacts of the consensus mechanism used to issue the crypto-asset.

Market in Crypto-Assets Regulation (MiCA) for token issuers

Art 66 (5): Obligation for all crypto-asset service providers:

(j) Crypto-asset service providers shall make publicly available, in a prominent place on their website, information related to the principal adverse impacts on the climate and other environment-related adverse impacts of the consensus mechanism used to issue each crypto-asset in relation to which they provide services (…).

Market in Crypto-Assets Regulation (MiCA) for CASPs

CCRI has published a methodology document[7] to assess the 10 mandatory sustainability indicators as proposed by the ESMA in the second consultation package for any type of consensus mechanism, on which the following sections build on. For the **calculation of the indicators of the Cardano network,** we highlight all sources used in this document. Our **live data feeds might use different sources in the future**. For an up-to-date list of sources, **please refer to CCRI's API documentation[8]**.

[7] https://carbon-ratings.com
[8] The documentation of CCRI's API can be found here: https://docs.api.carbon-ratings.com

2 INDICATOR OVERVIEW

The following table shows the ten sustainability indicators as proposed by the ESMA in the second consultation package and their description.

Type	Adverse Sustainability Indicator	Metric
Energy	Energy consumption	Total amount of energy used, expressed in kilowatt-hours (kWh) per calendar year, for the validation of transactions and the maintenance of the integrity of the distributed ledger of transactions
	Non-renewable energy consumption	Share of energy used generated from nonrenewable 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
	Energy intensity	Average amount of energy used, in kWh, per validated transaction
GHG emissions	Scope 1 - Controlled	Scope 1 GHG emissions, expressed in tonnes (t) carbon dioxide equivalent (CO2e) per calendar year for the validation of transactions and the maintenance of the integrity of the distributed ledger of transactions
	Scope 2 – 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
	GHG intensity	Average GHG emissions (scope 1 and scope 2) per validated transaction, expressed in kilogram (kg) CO2e per transaction (Tx)
Waste production	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, expressed in tonnes per calendar year
	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
	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, expressed in tonnes per calendar year
Natural resources	Impact of the use of equipment on natural resources	Description of the impact on natural resources of the production, the use and the disposal of the devices of the DLT network nodes

Source: ESMA, Consultation Package 2, Annex II, Table 1

3 ENERGY-RELATED SUSTAINABILITY INDICATORS

The first three indicators are energy consumption related. Indicator 1 captures the total energy used for the validation of transactions and the maintenance of the integrity of the distributed ledger. Indicator 2 quantifies the non-renewable share, and Indicator 3 the per transaction energy usage.
We described the methodology for assessing the electricity consumption of the network in detail in A. NETWORK ASSESSMENT METHODOLOGY. The results from this methodology can directly be used for indicators 1, 2, and 3.

4 GHG EMISSION RELATED SUSTAINABILITY INDICATORS

To derive the GHG emissions for the validation of transactions and the maintenance of the integrity of the distributed, two components are required: (1) the energy consumption and (2) the emission intensity of the energy consumed. Both components have already been established and serves as a direct input for this section.

Indicator 4 – Scope 1 - Controlled

For the fourth indicator, ESMA asks for scope 1 GHG emissions for the validation of transactions and the maintenance of the integrity of the distributed ledger of transactions. 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[9]. 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. We argue that a reasonable interpretation would be to think of 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., Staking Pool 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 electricity that is consumed, the GHG emissions would only be owned or controlled by the validators in case they are producing the electricity themselves. Given the amount of energy required for running an SPO, we would argue that it should be assumed that SPOs are purchasing the electricity they use (which represents scope 2 – see indicator 5), unless there is clear evidence that a power plant is owned or controlled by the validator itself. The associated emissions would then be calculated by taking the electricity consumed by the owned or controlled power plant and multiplying it by the emission intensity of the respective plant (i.e., largely driven by the type of power plant, for example solar PV vs. wind. vs. gas). As the MiCA regulation foresees sustainability disclosures on the level of a crypto-asset and not on company-level, any information on potentially independently operated or controlled power plants must be taken from public reports from validators.

We are not aware of any SPOs running their own power plants for their operations; therefore we assume zero Scope 1 emissions.

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

Indicator 5 – Scope 2 - Purchased

For the fifth indicator, ESMA asks for scope 2 GHG emissions for the validation of transactions and the maintenance of the integrity of the distributed ledger of transactions. Scope 2 is defined as indirect GHG emissions from emissions from the generation of acquired and consumed electricity[10]. In line with indicator 4, we would argue that a reasonable interpretation would be to think of the indirect GHG emissions of the acquired and consumed electricity of SPOs. Similar to most other industries, we would argue that the majority of the validators purchase the electricity they consume rather than producing it themselves. 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 (using mostly grid-average emission factor data). Therefore, the method requires the amount of electricity consumed at each location 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 electricity 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 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 GHG Protocol requires both methods to be reported separately if one decides to start calculating scope 2 emissions with the market-based method (termed "dual reporting").

For the Cardano network, we use only the location-based method to report scope 2 emissions as detailed information on renewable energy claims is currently unavailable to calculate market-based scope 2 emissions and perform "dual reporting".

Indicator 6 – GHG intensity

For the sixth indicator, ESMA asks for the average GHG emissions (scope 1 and scope 2) per validated transaction. This metric has already been derived in A. NETWORK ASSESSMENT METHODOLOGY.

5 WASTE PRODUCTION RELATED SUSTAINABILITY INDICATORS

Similar to the energy-related indicators, the first waste production related indicator captures the total amount of electrical and electronic equipment waste for the validation of transactions and the maintenance of the integrity of the distributed ledger. Indicator 8 then quantifies the non-recycled share, and Indicator 9 the hazardous waste fraction. Further details are provided below for each of the indicators.

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

Indicator 7 – Generation of waste electrical and electronic equipment (WEEE)

For the seventh indicator, ESMA asks for 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, the calculation of the total electronic waste can be conducted in two consecutive steps:

1. **Understand the hardware composition and weight of devices**: For the electricity consumption of the Cardano network, we made assumptions on the hardware composition, both on device type and distribution between devices. This hardware composition provides a solid basis for the calculation of the number of total devices in the network. We collected the respective hardware weights.

2. **Define the depreciation time frame**: If we know the hardware composition for a given day in the network, we are able to calculate the WEEE generated on that day with a given depreciation time frame.[11] As previously mentioned, deciding on the time frame can be complex and research in the regard of depreciation is sparse.

For the depreciation time frame of Cardano, we observe that the *Infrastructure Survey 2024* conducted by the Cardano Foundation draws a mixed picture of depreciation times, ranging from three to five years. To be on the conservative side of an estimate, we assume a hardware depreciation of three years.

Indicator 8 – Non-recycled WEEE ratio

For the eighth indicator, ESMA asks for the share of non-recycled WEEE. To calculate this metric, one needs to consider the location of validators as well as the local recycling rates for WEEE at the respective locations. Similarly, to energy sources and emission factors by country or region, local recycling rates can be obtained from state authorities or research institutions specialized in the field (e.g., United Nations Institute for Training and Research (UNITAR), UNU-ViE Sustainable Cycles (SCYCLE), The International Telecommunication Union (ITU) jointly publishes reports monitoring e-waste production and recycling).

Indicator 9 – Generation of hazardous waste

For the ninth indicator, ESMA asks for the hazardous waste generated by the network. As we calculated the waste component of the network already in indicator 7, 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.

The calculation of the share of the hazardous substances is merely a question of proper data sources and diligence. Ideally, for every device considered in the hardware composition described in Indicator 7, one

[11] 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).

obtains a "Restriction of Hazardous Substances Directive Report" (RoHS Report), which needs to be published by respective vendors. The contents of these documents need to be summed up for each device. With that information and the hardware depreciation, one is able to calculate the total hazardous waste generated by the network. If the ROHS Report is not available for every type of device in the network, similar device types for which the report is available can be used as a proxy.

6 NATURAL RESOURCES RELATED SUSTAINABILITY INDICATORS

The last category aims to capture lifecycle impacts on natural resources beyond the aspects captured by the previous indicators. For the tenth indicator, ESMA asks for a description of the impact on natural resources of the production, the use and the disposal of the devices of the DLT network nodes. While ESMA asks for very concrete metrics for the other indicators by defining exact time periods and units, this indicator is only loosely defined as of now. Thus, there is reason to assume that this indicator will be more closely defined as the ESMA publishes its final requirements for mandatory indicators (expected by the end of June 2024).

Indicator 10 – Impact of the use of equipment on natural resources

For the tenth indicator, we provide 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. 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. Thus, the electricity consumption, the location of validators as well as regional electricity water footprint may serve as an input to assess the water consumption of a crypto-asset during the use phase following the approach which is taken by research papers investigating the water consumption of Bitcoin[12].

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

D. MiCA INIDCATORS

The following table shows the 10 mandatory sustainability indicators as proposed by the ESMA in the second consultation package published in October 2023, annualized as of the measurement date. The indicators will be updated once the ESMA publishes the final regulatory requirements.

Type	Adverse Sustainability Indicator	Results
Energy	Energy consumption	**687,238.04 kWh**
	Non-renewable energy consumption	**69.12 %**
	Energy intensity	**0.000168 kWh**
GHG emissions	Scope 1 - Controlled	**0 t**
	Scope 2 – Purchased	**244.448 t**
	GHG intensity	**0.0000597 kg**
Waste production	Generation of waste electrical and electronic equipment (WEEE)	**8.26 t**
	Non-recycled WEEE ratio	**51.93 %**
	Generation of hazardous waste	**0.004237 t**
Natural resources	Impact of the use of equipment on natural resources	**Textual description**[13]

Cardano MiCA Sustainability Indicators, CC-BY 4.0 License

[13] Natural resources may include water usage, fossil fuels, or critical raw materials. Water usage is relevant for data center operations directly for cooling and indirectly through electricity consumption which is not based on wind or solar (Mytton 2021). Consequently, electricity consumed which is not based on wind or solar may also cause water usage during the production and disposal of hardware. Similarly, fossil fuel usage is relevant for the production, use and the disposal of hardware whenevery electricity is used since electricity consumption from fossil fuels still accounts for over 60% of global electricity production (IEA 2023). Critical raw materials are specifically relevant in the production of hardware as electrical and electrical and electronic equipment typically depend on technology metals that are classified as critical (Chancerel et al 2015). Extensive data collection is required to quantify the impact on water usage, fossil fuel usage, and critical raw materials of the devices of DLT network nodes. Thus, the impact on natural resources, such as water, fossil fuels, and critical raw materials of the production, the use and the disposal of the devices of the DLT network nodes is influenced by the amount of energy consumed, by the type of sources used to generate electricity and by the amount of hardware required by the network. For instance, the water consumption during the use phase of the Cardano network amounts to 3,646.37 kiloliters.

Appendix

HARDWARE-SPECIFIC MEASUREMENT RESULTS

Hardware configuration	1	2	3	4	5	6
CPU	Broadcom BCM2711	Intel i3-8109U	Intel i5-8400T	Intel i5-1135G7	Intel i5-10400	AMD 3970X
Ram	8 GB	8 GB	8 GB	16 GB	64 GB	256 GB
Storage	128 GB SD	512 GB SSD	256 GB SSD	2 TB SSD	2 TB SSD	2 TB SSD
Configurations selected	no	no	No	yes	yes	yes
Mean electrical power in idle [W]	3.031	2.688	2.893	3.675	25.304	80.464
Mean electrical power of node [W]	-	-	-	5.313	26.912	110.668
Assumed node distribution	-	-	-	45.0 %	45.0 %	10.0 %
Measurement period	2024-04-24 13:57:14. 752 CET to 2024-04-25 13:57:15.346 CET					
Software version	cardano-node 8.9.2, cardano-cli 8.20.3.0					

MICA INDICATORS-RELATED SOURCES

- **Indicator 2**: We use electricity generation mix data from IRENA (2023), Renewable energy statistics 2023, International Renewable Energy Agency, Abu Dhabi.
- **Indicator 5**: We use emission factors from the Environmental Protection Agency for U.S. states, from the Environmental Energy Agency for European countries and from Climate Transparency for all other G20 countries.
- **Indicator 8**: We use e-waste recycling rates from The Global E-waste Monitor 2024 by UNI/UNITAR and ITU.
- **Indicator 10**: We build on the methodology and data presented in de Vries, A. (2024). Bitcoin's growing water footprint. Cell Reports Sustainability, 1(1). to derive the water consumption of the use phase for the Cardano network. In the description, we refer to following citations:
  - Mytton, D. (2021). Data centre water consumption. npj Clean Water, 4(1), 11.
  - IEA (2023). Electricity. https://www.iea.org/energy-system/electricity#sources-of-electricity
  - Chancerel, P., Marwede, M., Nissen, N. F., & Lang, K. D. (2015). Estimating the quantities of critical metals embedded in ICT and consumer equipment. Resources, conservation and recycling, 98, 9-18.

About CCRI

CCRI – *Crypto Carbon Ratings Institute* – is a research-driven company providing data on sustainability aspects of cryptocurrencies, blockchain and other technologies. The interdisciplinary team has built a multi-year research track record with a specific focus on cryptocurrencies and their sustainability impacts. CCRI uses the most up-to-date data sources as well as methods based on formerly peer-reviewed studies published in renowned scientific journals. CCRI provides insights that help their clients to understand and manage crypto-related ESG exposure. They serve a broad range of clients including institutional investors, exchanges and blockchain networks.

CCRI

Crypto Carbon Ratings Institute (CCRI) is a brand of CCRI GmbH based in Dingolfing, Germany.