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REPORT

Energy Efficiency and Carbon Footprint of the **TRON Blockchain**

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Preamble

This commissioned report is prepared by CCRI for
TRON Network Inc.

Executive summary

- The electricity consumption and carbon footprint of Proof of Work (PoW)-based networks and cryptocurrencies such as Bitcoin and Ethereum remain significant.
- Existing research suggests that cryptocurrencies based on alternative consensus mechanisms such as Proof of Stake (PoS) are energy-efficient and consume much less electricity.
- This study assesses the electricity consumption and carbon footprint of the PoS cryptocurrency TRON.
- As of July 1st 2022, the yearly electricity consumption lies at **162,868 kWh**, the yearly carbon footprint at **69.47 tCO_2e**.
- The analysis of the TRON node locations has determined the carbon intensity of the network at **426.5 gCO_2e/kWh**, sitting slightly below the world average of 459 gCO_2e/kWh.
- The amount of electricity consumed by the TRON network equals the consumption of about **15 US households**.
- The total electricity consumption of the TRON network lies within the range of previously studied PoS blockchain networks.
- The marginal electricity consumption for a single transaction within the TRON network is **0.27 Ws per Tx**.

1 Introduction

The electricity consumption and related carbon footprint of Bitcoin and other cryptocurrencies are subject to extensive discussion in public, academia, and industry. For these protocols, various estimations exist, comparing Bitcoin's electricity consumption to different mid-sized countries (CBECI, 2022; de Vries, 2022). The problem has been known for several years, and other systems and technologies have emerged to solve the issue. The consensus family of Proof of Stake (PoS) is deemed superior regarding the electricity requirements compared to the traditional Proof of Work (PoW) consensus mechanisms (King & Nadal, 2012). While it is consensus in the broader scientific community that PoS does not exhibit the same electricity issues of PoW, the responsibility of individual PoS systems is typically less clear.

Instead of requiring computational power to solve mining puzzles for securing the network in PoW, PoS requires validators to lock in funds for a specific period of time to propose or vote on new blocks. Due to the nature of the software engineering process and network architectures, different PoS systems rely on varying fundamentals regarding the hardware requirements, programming language, network size, transaction throughput, transaction complexity, and more. These factors influence the electricity consumption and, therefore, the carbon footprint of a respective network. While it is expected that the overall differences between PoS networks are minor, it is nonetheless essential to understand the absolute and relative energy efficiency of single networks (Gallersdörfer, Klaaßen, & Stoll, 2020)[1]. Previous research, conducted by CCRI, calculated both the electricity consumption and carbon footprint of six Proof of Stake networks, namely Algorand, Avalanche, Cardano, Polkadot, Tezos, and Solana (CCRI, 2022b). There are also estimates for other PoS systems, albeit no actual hardware measurements took place (Platt et al., 2021).

Since an extensive analysis of the electricity consumption and carbon footprint is not yet available for the cryptocurrency TRON, this report examines the electricity consumption, carbon footprint, and influencing factors of the TRON Proof of Stake blockchain network. Table 1 summarizes the results.

	Nodes [# total]	Transactions [Tx/year][2]	Total electricity consumption [kWh/year]	Electricity per node [kWh/year]	Electricity per transaction [Wh/Tx][3]	Total carbon emissions [tCO_2e/year]
TRON	367	2.317 bn	162,867.85	443.78	0.07	69.47

Table 1: Overview of results based on measurement as of July 2022.

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[1] Transparency notice: This article was authored by the founders of CCRI.

[2] We assume the number of transactions occurred during our measurement period of one day to extrapolate to a yearly transaction count which is needed to contextualize the electricity consumption.

[3] The marginal electricity consumption per transaction is given in section 5.4.

2 Aim and scope

This report aims to provide insights into the electricity consumption and carbon footprint of the TRON PoS network. The methodology is described in detail in Chapter 3.

It is noteworthy that the approach applied in this report is a helpful tool to derive a ballpark estimate for total electricity consumption and carbon emissions as well as the relative performance. However, any PoS network is associated with uncertainties that impede deriving exact numbers of the electricity consumption or, respectively, of a network's carbon footprint. Numerous factors, such as the network size, varying hardware configuration, or network infrastructure, influence the overall electricity consumption. Nonetheless, we deem this report to produce the most precise electricity consumption and carbon footprint estimates for the TRON cryptocurrency, as we observe and measure the electricity consumption of single hardware components and use them as a proxy for the overall network.

The establishment of representative hardware, network sizes, and electricity measurements form the basis for future research, such as comparing different networks and their respective requirements and properties.

We investigate the TRON PoS network in our analysis, which takes the 16th position with regard to market capitalization of coinmarketcap.com on 18th July 2022[4]. We summarize important key figures for the TRON cryptocurrency as per the specified date in the following:

- **Name:** TRON
- **Symbol:** TRX
- **Market Capitalization (Rank):** $ 6,446,875,892 USD (16th)
- **TRON Price:** $ 0.06974 USD
- **Circulating Supply:** 92.44 B TRX
- **24 Hours Trading Volume:** $ 620,503,580 USD

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[4] https://coinmarketcap.com/historical/20220718/

3 Methodology

Our methodology builds upon four steps to generate data on the electricity consumption and carbon footprint of the TRON PoS system. We develop metrics to enable a valid comparison between previous analyzed PoS systems (see CCRI (2022b)).

In the **first step**, we analyze the TRON PoS network and its minimum hardware requirements. The hardware requirements 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.

In the **second step**, we estimate the electricity usage of a single node and provide upper and lower bounds for the network. We start by running the software on all obtained hardware devices and measure their single electricity consumption while running the network and while idling. We also measure other data points, such as CPU utilization and processed blocks, to be able to evaluate additional metrics. These values allow us to produce reasonable upper and lower bounds for running a single node, as our hardware is selected accordingly.

In the **third step**, we estimate the electricity consumption of the complete network. Firstly, we collect information about the size of the network, as the node count significantly influences the amount of electricity consumed. Secondly, we develop a weighting between the single hardware devices for each network. Lastly, we multiply the electricity consumption of the weighted nodes by the number of nodes in the network. Since the distribution of nodes in the network is available, we use the derived carbon intensity factors of the respective regions to calculate the carbon footprint.

In the **fourth step**, we analyze additional data (such as transaction and block information) to develop further metrics to explore energy efficiency in transaction throughput. We take samples of the nodes’ electricity consumption periodically and examine the number of transactions that were handled by the single nodes 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. As a result, we establish a model to estimate a node’s power consumption based on the number of transactions. This enables us to put the electricity consumption of the TRON network into perspective with other PoS networks and also other cryptocurrencies such as Bitcoin and Ethereum.

4 TRON hardware requirements and test environment

In this chapter, we first establish our selected hardware pool for carrying out analyses of PoS networks. Secondly, we summarize the hardware requirements for a node participating in the TRON network. Thirdly, we provide details of the infrastructure required to measure electricity consumption and further describe our test environment.

4.1 Hardware selection

For analyses of PoS systems, we generally define three different categories of hardware requirements for nodes participating in a network:

- **Low hardware requirements:** For PoS networks with rather low hardware requirements, we assume that computational power is not a concern for the systems, and users should be comfortable running the software on any system they have available. Typically, such networks recommend using low-energy hardware for running nodes, as for example the well-known Raspberry Pi. In today's average consumer desktop PC, 4-8 GB RAM and 200 GB of storage (even an SSD) are not uncommon anymore.
- **Specific hardware requirements:** Some networks specify quite precise hardware requirements, for instance stating the exact CPU type as well as RAM and storage. For such networks, we normally aim for using hardware that satisfies the requirements, but we also test hardware that does not meet the recommendations if they are able to run a node reliably and include these tests in our calculation. Nonetheless, hardware requirements typically give users who intend to run a node an indication about what to expect regarding demand, influencing their final choice of hardware.
- **High hardware requirements:** Some few PoS systems exhibit surprisingly high hardware requirements. The CPU, RAM, and storage requirements can be at the highest level of standard desktop computers (besides servers). Graphic cards can be required in such networks, which hints at the immense processing power required.

We define a hardware pool that covers the above-mentioned categories in order to ensure a high degree of hardware diversity. For the analysis of specific networks, it is important to decide on a case-by-case basis which hardware configurations to use. Based on the hardware requirements, both an upper and a lower bound of hardware are evident.

For the lower bound, we select a Raspberry Pi 4 Model B with 8 GB RAM and 128 GB SD-card given that the popularity of the Raspberry Pi computers is high within all communities. We opt for an official Raspberry Pi full kit, including fan and power supply.

As an upper bound, we opt for an average system within the Threadripper specifications consisting of an AMD Ryzen Threadripper 3970X, 32C/64T, 256GB RAM (DDR4-3600), and a Samsung 970 Evo Plus 2TB in order to address high hardware requirements. As the processor does not have an onboard graphics processor, we need a graphics card. However, as graphics cards are not always required at that time, we opt for a card that does not support CUDA and cannot participate in the calculations of any network. We select an appropriate mainboard as well as a power supply.

The upper and lower bounds highly deviate from each other in terms of computational power and electricity consumption. Further, the two computers may not capture the complete picture of the hardware used within networks to be analyzed. Therefore, we decided to add four additional computers to ensure a well-balanced set of hardware for electricity consumption measurements.

As there are millions of different computer configurations, thousands of variables, and other factors that influence the electricity consumption of devices, we opt for one key variable and derive other specifications of the system from it: The central processing unit (CPU). Nonetheless, the CPU also has several variables such as the number of cores, threads, speed, turbo speed, thermal design power (TDP), and others. Further, identical variables do not necessarily lead to the same computational power or electricity consumption. To get an in-depth view and understanding of the CPU landscape, we obtain a data set from PassMark. PassMark provides a software suite able to benchmark varying types of hardware, including CPUs. The obtained data set contains over 3,100 CPU models as well as over 1 million results of their benchmarking suite (Passmark Software, 2021). Based on this data set, we select four CPUs to derive our final configurations. We thereby aim at three categories of performance (high, mid, and low) and select one or more CPUs with the average efficiency for their class. A detailed description of our approach to select CPUs can be found in Appendix A.

For the high-tier (configuration 5), we identified the Intel Core i5-10400F as being closest to the average efficiency. As Intel's F-models only have a deactivated onboard graphics chip (Intel, 2021), we decided to opt for the non-F variant, as otherwise, a dedicated GPU would add unnecessary electricity consumption to the system. The non-F variant is almost identical to the F variant regards to benchmarking results. We opted for 64 GB DDR4 RAM and a Samsung 970 Evo Plus 2 TB NVMe SSD to complement the system. Mainboard, power supply unit, and case have been selected appropriately.

Regarding the mid-tier section, we have extended our hardware selection with an additional device compared to our previous measurements (CCRI, 2022b), as we assume that most standard users apply hardware from this range. Since the Intel NUC series is becoming increasingly popular for running blockchain nodes, we decided on an Intel NUC with medium equipment (configuration 4). We chose an Intel Core i5-1135G7 laptop processor with included graphics chip, which represents the upper mid-range of typically used devices quite well. This additional mid-tier computer is equipped with a 32 GB DDR4 RAM and a 2 TB NVMe SSD. Furthermore, we still stick to the Intel Core i5-8400T since it has the best fit for the average electricity consumption in the mid-tier section (configuration 3). The T-model means the CPU has a "power-optimized lifestyle", resulting in lower performance and less electricity consumption. We could not directly obtain the CPU in the market and instead opted for a completed build: The Lenovo ThinkCentre M720q Tiny 10T8S3KD00. Besides the processor as mentioned above, it includes a 256 GB NVMe SSD as well as 8 GB RAM.

In the low-tier section (configuration 2), we identify the Intel Core i3-8109U as the processor with an average energy efficiency for its class. The U-label refers to a "Mobile power-efficient" CPU but is nonetheless included in MiniPCs. To our knowledge, this CPU was never sold separately on the consumer market but is available in Intel's NUC series. We obtain the Intel NUC Kit NUC8i3BEK2 Barebone and augment it with the Samsung 970 Evo Plus 512 GB NVMe SSD as well as 8 GB RAM.

To ensure comparability with our previous analyses of other PoS systems, we largely stick to the same hardware selection as defined in CCRI (2022b). However, some minor adjustments to better fit the assumed hardware diversity in the TRON network have been conducted. Besides including a further mid-tier setup into the hardware pool with configuration 4, configuration 5 was enhanced regarding both RAM and storage capacity ensuring a significant difference to the new configuration 4 not only in terms of the CPU.

We consider our selection as representative to provide a balanced set of hardware for electricity measurements with these six computers. As an operating system, we use for all our devices Ubuntu Server 20.04, except for configuration 5. Due to driver issues, we had to opt for Ubuntu Server 21. Table 2 displays an overview of the hardware configurations just introduced. Other factors than CPU are also relevant for the electricity consumption of the systems. Nonetheless, this set of hardware yields a broad overview of used hardware within such networks.

	1	2	3	4	5	6
CPU	Broadcom BCM2711	Intel i3-8109U	Intel i5-8400T	Intel i5-1135G7	Intel i5-10400	AMD 3970X
Cores/Threads	4/4	2/4	6/6	4/8	6/12	32/64
Architecture	ARM	x86/x64	x86/x64	x86/x64	x86/x64	x86/x64
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
GPU	Onboard	Onboard	Onboard	Onboard	Onboard	AM 6970
PSU	USB-C	65 Watt	65 Watt	65 Watt	650 Watt	1000 Watt
Case	Integrated	Integrated	Integrated	Integrated	Custom	Custom
OS	Ubuntu 20.04	Ubuntu 20.04	Ubuntu 20.04	Ubuntu 20.04	Ubuntu 21	Ubuntu 20.04

Table 2: Overview of selected hardware configurations from lowest to highest requirement

4.2 Hardware requirements of TRON PoS network

Compared to the hardware requirements of the PoS systems previously analyzed (CCRI, 2022b), those for nodes participating in the TRON network are comparatively advanced. Unlike other PoS systems, different hardware requirements are recommended for TRON, depending on whether the user runs a regular full node or a so-called "Super Representative", i.e., a validator node. Table 3 summarizes the recommended hardware for executing TRON at the time of our analysis (July 2022).

	TRON (Full Node)	TRON (Validator)
CPU	16 cores	32 cores
RAM	32 GB	64 GB
Storage	1.5 TB	1.5 TB
Bandwidth	100 MBit/s	100 MBit/s

Table 3: Hardware requirements of TRON PoS network

Applying these requirements for executing a TRON full node to our hardware pool as presented in the previous section, we deduce that configurations 5 and 6 fulfill and even exceed the hardware recommendations. Consequently, these configurations are chosen to be included in our analysis. Moreover, since we avoid treating hardware recommendations as a strict border, we also involve configuration 4 into our experiment to examine a representative of the mid-tier category. Since this computer almost meets the requirements for a TRON full node, we assume a basically stable operation. Table 4 summaries which nodes of our hardware pool were included in the experiment for the TRON network.

	TRON
Configuration 1	✗
Configuration 2	✗
Configuration 3	✗
Configuration 4	✓
Configuration 5	✓
Configuration 6	✓

Table 4: Overview of nodes of our hardware pool selected for running a TRON full node

4.3 Infrastructure for electricity measurements

For the measurement of the electricity consumption, we use a *Mystrom WiFi Switch* for each computer. These switches measure the electricity consumption as well the room temperature and provide the values over a REST interface. The electricity measurements are made in Munich, Germany in a separate server room with near-constant room temperature.

All devices were equipped with the same software, a new Ubuntu server 20.04/21 installation, and the monitoring tool Glances (Hennion, 2021) that allows us to collect additional system information such as temperature or system load during the experiment.

A separate Raspberry Pi, equipped with a Python script, collected and monitored the systems during executing the TRON full nodes and analyzed the data generated during the runs. All computers are only connected to the power outlet and LAN. All systems share an internet connection with 350 Mbit/s download and 110 MBit/s upload.

5 Electricity consumption and carbon footprint of the TRON Proof of Stake network

The definition of the to-be used hardware allows us to establish single node measurements. With these measurements, we provide upper and lower bounds for the electricity consumption of a single node and the best guess as a weighted average between the selected computer devices. On that basis, we establish the electricity consumption of the overall TRON network and discuss additional metrics such as the electricity use per transaction.

5.1 Single node measurements

After defining and obtaining the hardware required for our analysis, we set up the hardware and install the node software for the TRON network. For that, we use the following process:

- **Hardware Setup**: We install the node with the respective Linux version, configure Glances and configure remote access.
- **Idle Measurement**: We run the idle measurement for the devices without any additional software installed.
- **Node Setup**: We download and install the software necessary for executing TRON and verify the correct installation.
- **Node Bootstrap**: We wait for every node to be fully synced, as we do not want to skew the electricity consumption of the devices during the bootstrapping phase.
- **Electricity Measurement**: We shut down the node, start the electricity measurement and then start the node again. The node runs for 24 hours, as this covers an entire day cycle. Appendix B contains an overview of every electricity measurement.

To understand what exactly we are measuring, we need to describe the TRON network and its setup. It consists of nodes, either validators (participating in the consensus protocol and producing new blocks) or regular full nodes (broadcasting and verifying regular transactions). There are 27 *Super Representatives (SRs)*, which are responsible for producing blocks and packing transactions. An additional 100 validators are referred to as *Super Partners (SP)*, which receive rewards without having to produce blocks; all other validators are labeled as *SR Candidates*. The total votes of all TRON holders on validators determine whether the respective validator is an SR, SP or a SR candidate. We would differentiate between full nodes and validators in an ideal setup, as they have slightly different roles and responsibilities within the network, however, on the Main network, significant stakes are required to run a validator. Furthermore, previous research suggests that participating in the PoS consensus mechanism has only a negligible effect on the device's electricity consumption (Sedlmeir, Buhl, Fridgen, & Keller, 2020). Therefore, we run our electricity measurement on regular full nodes running on the TRON Main network.

5.1.1 Idle electrical power

We measure the electricity consumption of the devices idle. Table 5 depicts the minimum, maximum, median, and the first and third quartile of the electricity consumption for 24 hours. All values are rounded to one decimal. Interestingly, the setup 2 and 3 consumes less electricity than the Raspberry Pi (configuration 1), which we deemed the most energy-efficient solution beforehand.

	1	2	3	4	5	6
Min [W]	2.9	2.6	2.6	3.6	24.5	77.5
Q1 [W]	3.0	2.6	2.9	3.7	24.8	77.9
Median [W]	3.0	2.7	2.9	3.7	24.9	78.0
Q3 [W]	3.0	2.7	3.0	3.7	25.1	78.3
Max [W]	3.9	17.8	17.3	4.4	26.6	118.1

Table 5: Electrical power in Idle measured in Watt [W] – hardware selection for each of the six clusters can be found in Table 2

5.1.2 Node electrical power

Due to the hardware requirements outlined in chapter 4.2, we do not run TRON on all nodes. While the hardware setups 5 and 6 of Table 2 exceed the recommended configurations for executing a TRON full node, we also test configuration 4 as we do not want to enforce the hardware requirements as a strict lower bound. We exclude hardware clusters 1, 2 and 3 from our measurements since these clearly do not satisfy the requirements provided by TRON.

In Table 6, we outline the mean and the median electrical power of the nodes during the measurement. There is no value available for those configurations not sufficient for executing TRON.

	1	2	3	4	5	6
Mean	N/A	N/A	N/A	16.80	31.18	123.50
Median	N/A	N/A	N/A	15.81	29.65	122.19

Table 6: Mean and median electrical power of nodes in Watt [W]

5.2 Calculation of bounds for electricity consumption

To calculate the electricity consumption of the overall network, we need to understand the average calculation for a single node. We measured the electrical power for three different computers. With these measurements for the electricity consumption, we can provide upper bounds, meaning the highest electricity that a node consumes, lower bounds, the least electricity a node consumes, and a best guess that captures the consumption of the average node best for the network.

5.2.1 Upper and lower bound

The upper and lower bound are measured by the least efficient and most efficient hardware, respectively. The lower bound therefore is constituted by configuration 4 from Table 2. Accordingly, configuration 6 serves as an upper bound. These bounds are summarized in Table 7.

	TRON
Lower bound [W]	16.80
Lower bound [kWh / year]	147.17
Upper bound [W]	123.50
Upper bound [kWh / year]	1,081.86

Table 7: Overview of lower and upper bounds of electrical power and electricity consumption per single node

5.2.2 Best guess

The electricity consumption of an average node in the network is challenging to estimate. There is no empirical data on the concrete hardware that nodes are running on or indicating user's preferences. For node owners, several factors are relevant for their decision on which hardware to run their node on. First, owners stake tokens to receive rewards and want their revenue to be stable, aiming for hardware designed for long-term operations. Second, due to the profit structure, they do not intend to spend all their revenue on hardware and might rather opt for sufficient hardware within the hardware requirements. These thoughts might influence their decision in one way or another but might not directly translate to a hardware selection. Therefore, we opt for a binomial distribution for the hardware selection, based on a regular distribution for key questions. The distribution for each hardware type is displayed in Table 8.

	TRON
1	N/A
2	N/A
3	N/A
4	25.00 %
5	50.00%
6	25.00 %

Table 8: Overview of node distribution for the six networks

With this distribution, we calculate the weighted electricity consumption of an average node:

$$\sum_{i \in hardware} avgEnergyConsumption_i * share_i$$

Not only the number of nodes is relevant for the electricity consumption of a PoS network, but also the underlying software and its requirements. Table 9 gives an overview about the best guess electricity consumption for the TRON network.

	TRON
Best guess [W]	50.66
Best guess [kWh / year]	443.78

Table 9: Best guess estimates for electrical power and electricity consumption of TRON network per single node

5.3 Electricity consumption of the network

We apply our lower bound, upper bound as well as our best guess at the number of nodes in the TRON network. We obtain the number of nodes from a block explorer as specified in Appendix C. The results are depicted in Table 10.

	TRON
Validator count	367
Electrical power of network [W]	18,592.22
Consumption / day [kWh]	446.21
Consumption / year [kWh]	162,867.85

Table 10: Overview of electricity consumption of the TRON network applying the best guess estimate

We find that the electricity consumption of the network amounts to 162,867.85 kWh annually in our best guess.

5.4 Electricity consumption per transaction

An often-used metric in comparing electricity consumption between systems is the electricity consumption per transaction. This allows comparing systems that have different architectures, transaction throughput, and electricity requirements. Nonetheless, companies that want to report emissions associated with cryptocurrency exposure should not necessarily rely on a transaction-based allocation approach and but should also consider other methodologies in order to avoid potential underreporting (Gallersdörfer, Klaaßen, & Stoll, 2021)[5].

The complexity of this metric is based on the fact that some systems provide a theoretical electricity consumption per transaction, simulating the network at full speed. Other calculations are based on transaction rates measured in the networks, making comparisons skewed. Further, the definition of a transaction might vary from network to network.

An additional complexity is the attribution of the electricity consumption solely to the transactions. The system requires a base electricity consumption to keep up with the consensus without providing any transactions. Nonetheless, given the base load of a network, running a node in a "low-transaction"-period might yield higher electricity per transaction costs than usually to be expected. While this metric provides a straightforward insight into different protocols, its base assumptions need to be understood and its results must be treated with care.

Lastly, the electricity consumption per transaction is only a single metric describing the sustainability of a network. It is of utmost importance to understand that this metric needs to be seen in the context of other metrics such as decentralization, security, transaction complexity, state size and others. This metric alone is not sufficient to decide whether a cryptocurrency is sustainable or if a cryptocurrency is worth investing in; in an extreme case, a network consisting of a single, high-performance computer, would be the most sustainable cryptocurrency, however making nonsense of the decentralization idea.

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[5] Transparency notice: This article was authored by the founders of CCRI.

As we measured the electricity consumption of our nodes in real-world scenarios, we also apply the transaction numbers that took place during the respective time period. Again, we weigh the single nodes for the overall network applying the previously described binomial distribution.

	TRON
Wh/tx per node	0.0001915
Wh/tx per network	0.07028
Number of tx	6,348,029

Table 11: Best guess electricity consumption of TRON on a per-transaction basis.

As expected, this metric depends on the number of transactions taking place on the blockchain, also the overall electricity consumption per transaction further depends on the number of nodes connected to the TRON network. Generally, these numbers are expected to go down with an increase in the transaction rate, regardless which blockchain is in use.

Another approach to estimate a node's and thus the network's electricity consumption based on the number of transactions is to rely on a statistical regression model. This methodology typically allows for more accurate results than merely considering average values. Furthermore, it has the advantage that constant power consumptions, which are independent of the transaction count, can be included in the model (e.g., the node's idle power consumption to be represented as the y-axis intercept). The regression model can be set up completely on the basis of our own measurements. We only consider elements in the data set for values $-2 \leq Z \leq 2$ applying a Z-score methodology to filter outliers.

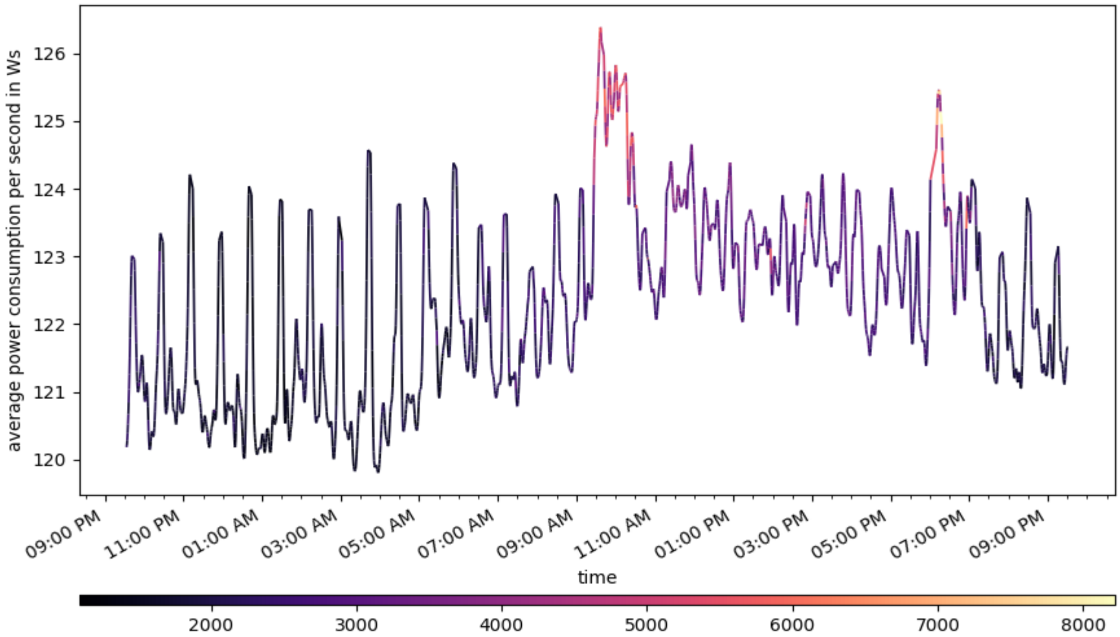

Figure 1: Average power consumption in Ws of hardware configuration 6 (y-axis) over time of measurement (x-axis). The color of the line represents the transaction count at the corresponding point in time.

Figure 1 indicates the power consumption of hardware configuration 6 (see Table 2) over the course of the measurement time frame. As a third dimension, the coloring of the line depicts the number of transactions that the node processed at the respective point in time. A clear relation between the number of transactions and electricity consumption is not always apparent. This might be explained by untypically complex transactions that can increase power consumption. However, a significant change in the line color can be recognized in the area from about 9 AM to 11 AM and at about 6:30 PM, accompanied by an increase in power consumption. At these points, the higher power consumption can most probably be explained by the higher number of transactions.

For this reason, we constructed a regression line for each of the three hardware configurations, based on our periodically taken measurement samples (every 30 seconds) that consist of the current power consumption and the number of transactions to be processed at that time.

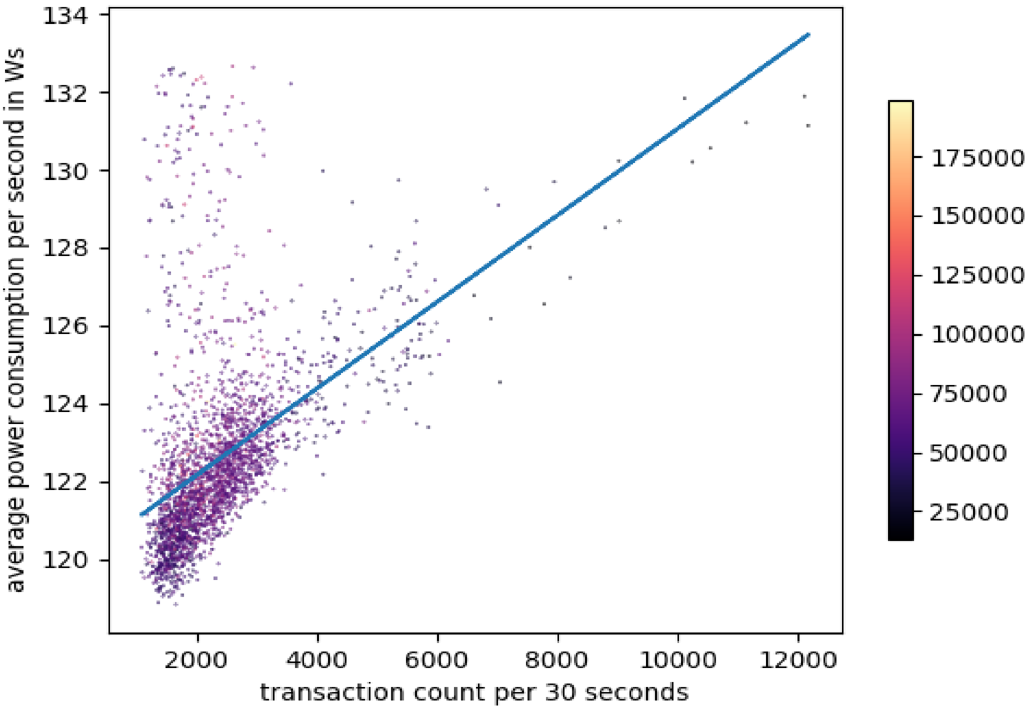

Figure 2: Plotted samples consisting of average power consumption per second in Ws (y-axis) and number of transactions processed per 30 seconds (x-axis) taken for hardware configuration 6. The color of the points indicates the average complexity (energy usage) of the transactions belonging to the corresponding sample. The resulting regression line to estimate the node's power consumption for an arbitrary amount of transaction is drawn in blue.

As an example, Figure 2 provides the regression line to estimate the power consumption of hardware configuration 6 for any given number of transactions. The model reveals a clear increase in power consumption with a rising number of transactions.

Based on this approach, we can establish a linear equation for a regression line to predict the power consumption (P_{BG}) for a given number of transactions (tx_{count}) for a best guess node operating in the TRON network. For this, we calculate the idle consumption of a best guess node based on the distribution of Table 9 and apply the resulting value as the y-axis intercept (t_{BG}) in the model. Likewise, to determine a general slope (m_{BG}) for a best guess node, we weight the slopes of the regression lines emerging for the three hardware configurations measured. As a result, we obtain the following linear regression equation to determine the power consumption of a best guess validator node in the TRON network depending on the number of transactions the node processes:

$$P_{BG}(tx_{count})\,[Ws] = m_{BG} * tx_{count} + t_{BG} = 0.000724543 * tx_{count} + 48.006387762$$

Multiplying the best guess marginal electricity consumption of a single node (m_{BG}) with the validator count of the TRON network, we obtain an overall best guess for a single transaction's marginal electricity consumption of the whole network for the time of measurement of 0.2659 Ws, as Table 12 summarizes:

	TRON
Validator count	367
Marginal electricity consumption per tx of single node [Ws]	0.0007245
Marginal electricity consumption per tx of network [Ws]	0.2659073

Table 12: Overview of marginal electricity consumption of the TRON network applying the best guess estimate

5.5 Carbon footprint of TRON

The electricity consumption of any system has no direct environmental impact, as mere usage does not cause any emissions. However, the impacts due to the potential emissions of the underlying energy sources may cause damage to the environment and need to be considered for sustainable business operations.

Depending on the underlying energy sources, the respective carbon footprint of the electricity consumption can vary. For a precise estimate of the carbon footprint, two pieces of data are essential: The location of the electricity consumers as well as the carbon intensity of the respective grid.

There are several ways for local electricity consumers to claim that their electricity consumption is carbon neutral. This includes corporate Power Purchase Agreements (PPAs), unbundled energy attribute certificates (EACs) – also often referred to as Renewable Energy Certificates (RECs) – , or off-grid electricity production for self-consumption. As we do not have any information on whether or to what extent the electricity consumption of the TRON network is backed by such instruments, we rely on the average grid intensity factor. As these instruments are also often aimed at energy-intensive industries or large corporations, we find the application of the average grid intensity factor to be plausible for a solid estimate of the carbon footprint of the TRON network.

Previous research localized nodes in other protocols by relying on internet search machines aimed at ASIC devices, IP addresses, or pool addresses. These approaches allowed for an estimate of how the nodes are distributed worldwide. For TRON, TRONSCAN collects information on the node location and presents them on their website (TRONSCAN, 2022). As it is unclear which of these nodes are actual validator nodes, we calculate the overall network carbon intensity and apply this carbon intensity to the electricity consumption of the validator nodes. Figure 3 displays the node locations on the world map.

Figure 3: Node Distribution of the TRON network (TRONSCAN, 2022)

$$\sum_{i \in node} EnergyConsumption_i * CarbonIntensity$$

Utilizing *Carbon Footprint*'s location specific emission factors, we calculate the average carbon intensity of the country in which the node is located. For the U.S., which represents 9.42 % of all nodes in the dataset, we resort to state level carbon intensities (carbon footprint, 2022). For unavailable carbon intensities and unavailable node locations, we assume the world average of 459 gCO_2e/kWh in accordance to the IEA (International Energy Agency, 2021). This is the case for 4.1 % of all nodes in the dataset. We calculated the carbon intensity of the network to be 426.5 gCO_2e/kWh. With that, we derive the carbon footprint of the network. The respective values are depicted in Table 13.

TRON	CO_2e emissions / year [t]
Lower bound	23.02
Best guess	69.47
Upper Bound	169.34

Table 13: Overview of CO_2e emissions of the networks on an annual basis as of time of measurement (July 2022)

6 Discussion and comparison of results

In the previous chapters, we introduced our methodology and conducted measurements to derive the electricity consumption and carbon footprint of the TRON Proof of Stake network. In this chapter, we contextualize the results of our work.

6.1 Yearly electricity consumption in the context of other systems

The electricity consumption of a single network is often meaningless without a context to compare the system. In Chapter 5, we outline that the yearly electricity consumption of the network amounts to 162,868 kWh. An average US household consumes about 10,600 kWh per year and therefore, the TRON network consumes about 15.4 times the electricity (U.S. Energy Information Administration, 2021). In comparison to the PoW-based cryptocurrency Bitcoin, the PoS network consumes less than 0.001 % of the Bitcoin network assuming a yearly consumption of 83.87 TWh as of the 01st July 2022 (CBECI, 2022). Bitcoin consumes much more electricity than Proof of Stake systems due to its Proof of Work consensus mechanism, resulting in the deployment of energy-intensive hardware. In Figure 4, we compare the Bitcoin network, the Ethereum network assuming a yearly consumption of 22.37 TWh as of the 01st July 2022 (CCRI, 2022a), TRON, further PoS networks we have previously analyzed in CCRI (2022b), and the average US household. Note that the networks shown in gray are limited in their comparability given the earlier time points of the analyses (conducted in August to October 2021).

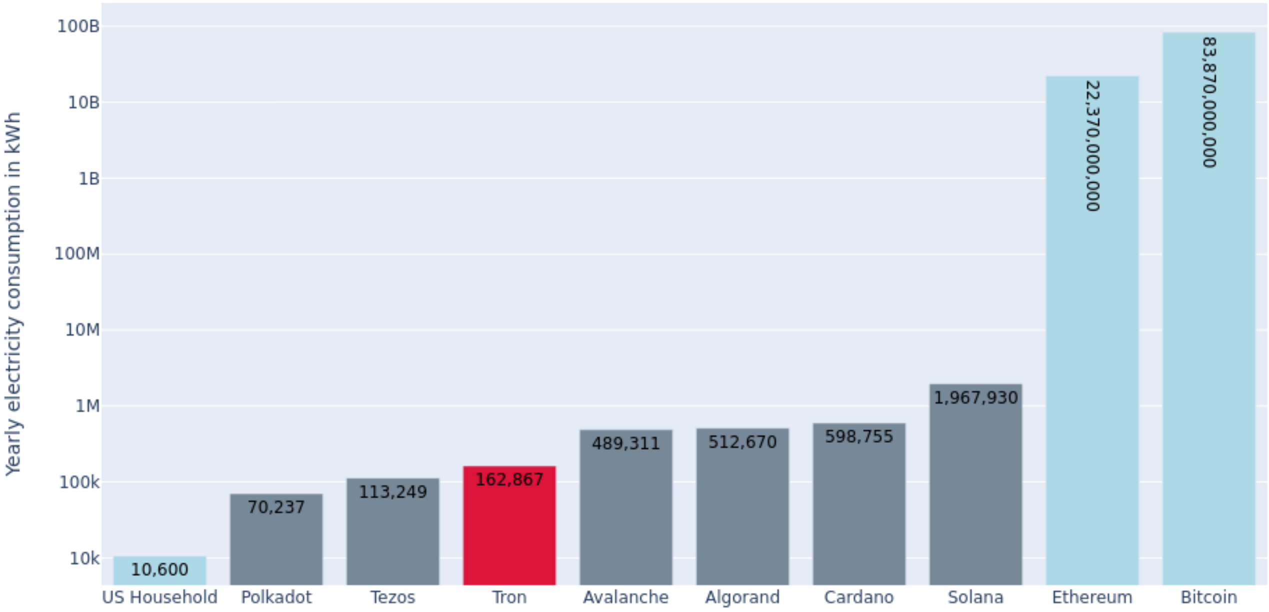

Figure 4: Yearly electricity consumption for Bitcoin, Ethereum, Proof of Stake networks TRON, Polkadot, Tezos, Avalanche, Algorand, Cardano and Solana, and an average US household in kWh. Logarithmic scale. Networks shown in gray are limited in their comparability given the earlier time points of the analyses (conducted in August to October 2021).

6.2 The carbon footprint of Proof of Stake networks

Overall, the emissions of the PoS networks are very low. As outlined in Chapter 5, the TRON network emits 69.47 tonnes of CO_2e yearly. For example, eleven round trips from Munich (MUC) to San Francisco (SFO) in business class emit about the same amount of carbon dioxide (MyClimate, 2021) produced by the TRON network. It can be assumed that the carbon emissions of companies behind the networks are higher than the emissions from the network itself (e.g., due to business travel). Figure 5 compares the carbon footprints of TRON and the six furth PoS networks from our previous research and to a roundtrip MUC – SFO in business class. As in the previous section, the gray-colored networks are only comparable to a limited extent due to the earlier time points of the analyses.

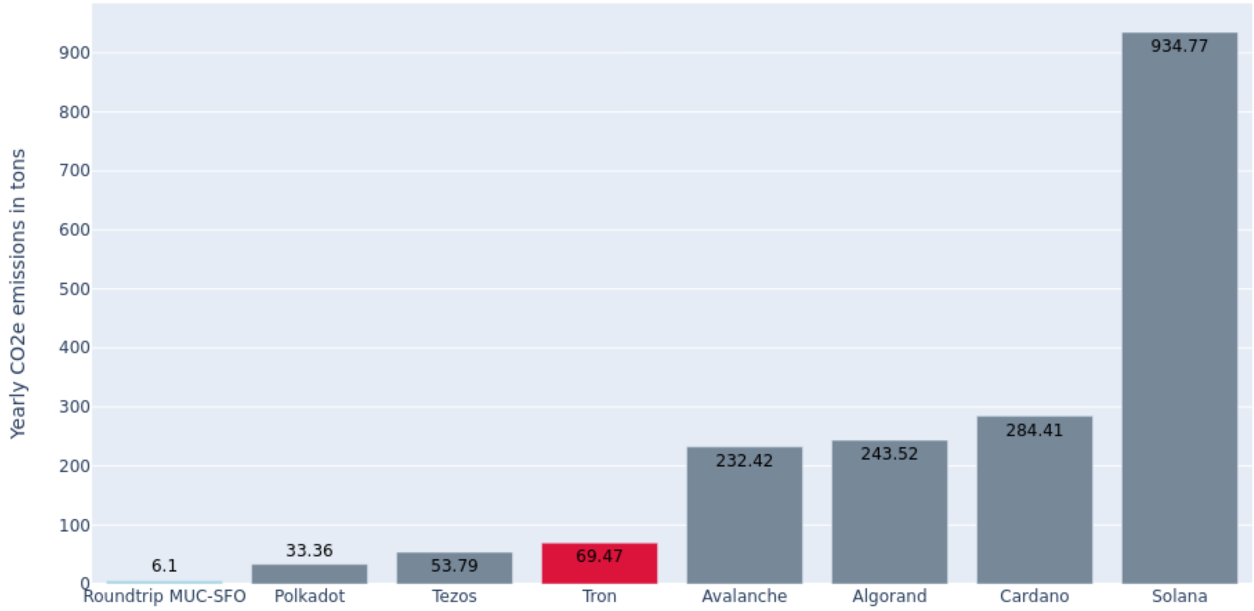

Figure 5: Yearly carbon footprint of TRON compared to other PoS networks and to a roundtrip flight in business class. Networks shown in gray are limited in their comparability given the earlier time points of the analyses (conducted in August to October 2021).

7 Conclusion

In this report, we outline an approach for calculating the electricity consumption and carbon footprint of the TRON network. We selected hardware, made measurements of the protocol, and calculated the respective metrics. We discussed our results and introduced several other key metrics, such as the Bitcoin and Ethereum network for comparison.

Our best guess estimates the yearly electricity consumption of the Proof of Stake network to be 162,867.85 kWh. This results in a carbon footprint of 69.47 tonnes of CO_2e annually. Compared to other electricity consumers such as an average US household, the network consumes roughly 15 times more electricity, and produces 11 times the amount of an intercontinental round trip flight.

Given the continuous development and evolution of Proof of Stake networks, our results can only be taken as a snapshot of the respective timeframe. Further measurements and analyses are required to update and further enhance the validity of the metrics for electricity consumption and carbon footprint of Proof of Stake and other networks. Additionally, other networks employing different consensus mechanisms as well as second layer networks need to be taken into account to gain a holistic picture of the environmental impact of cryptocurrencies and tokens.

In recent years, Bitcoin has faced harsh criticism for its electricity demand and carbon emissions. In the public, these fears and accusations have often been applied to other blockchain protocols, regardless of their technical foundations or capabilities, harming the adoption of blockchain protocols in the industry, public sector, and private investors (Rieger, Roth, Sedlmeir, & Fridgen, 2022). Based on the emissions calculated for the TRON network, one may conclude that Proof of Stake-based blockchain protocols consume an amount of electricity that does not justify the discussions about their environmental footprints at current levels. Nonetheless, further monitoring of the situation and analysis is required as Web3 and blockchain technologies receive increased attention and usage. Furthermore, an extensive perspective, including corporate footprints and the ecosystem, must be taken. For practitioners selecting a PoS blockchain protocol, other factors such as decentralization, network throughput and functionality (e.g., Smart Contracts) should play a vital role as decision criteria.

8 References

carbon footprint. (2022). *Country Specific Electricity Grid Greenhouse Gas Emission Factors*. Retrieved from https://www.carbonfootprint.com/docs/2022_03_emissions_factors_sources_for_2021_electricity_v11.pdf

CBECI. (2022). Cambridge Bitcoin Electricity Consumption Index. Retrieved from https://cbeci.org

CCRI. (2022a). CCRI Cryptocurrency Sustainability API. Retrieved from https://docs.api.carbon-ratings.com

CCRI. (2022b). *Energy efficiency and carbon emissions of PoS Networks.* . Retrieved from https://carbon-ratings.com/dl/pos-report-2022

de Vries, A. (2022). Bitcoin Energy Consumption Index. Retrieved from https://digiconomist.net/bitcoin-energy-consumption

Gallersdörfer, U., Klaaßen, L., & Stoll, C. (2020). Energy consumption of cryptocurrencies beyond bitcoin. *Joule, 4*(9), 1843-1846.

Gallersdörfer, U., Klaaßen, L., & Stoll, C. (2021). Accounting for carbon emissions caused by cryptocurrency and token systems. *arXiv preprint arXiv:2111.06477.*

Hennion, N. (2021). Glances - An eye on your system. Retrieved from https://github.com/nicolargo/glances

Intel. (2021). Intel® Processor Names and Numbers. Retrieved from https://www.intel.com/content/www/us/en/processors/processor-numbers.html

International Energy Agency. (2021). World Energy Outlook. Retrieved from https://www.iea.org/reports/world-energy-outlook-2021

King, S., & Nadal, S. (2012). Ppcoin: Peer-to-peer crypto-currency with proof-of-stake. *self-published paper, August, 19*(1).

MyClimate. (2021). Carbon Footprint calculator. Retrieved from https://co2.myclimate.org/en/flight_calculators/new

Passmark Software. (2021). Hardware & Software Market Trends. Retrieved from https://www.passmark.com/services/market-analysis.php

Platt, M., Scdlmeir, J., Platt, D., Xu, J., Tasca, P., Vadgama, N., & Ibañez, J. I. (2021). *The Energy Footprint of Blockchain Consensus Mechanisms Beyond Proof-of-Work.* Paper presented at the 2021 IEEE 21st International Conference on Software Quality, Reliability and Security Companion (QRS-C).

Rieger, A., Roth, T., Sedlmeir, J., & Fridgen, G. (2022). We need a broader debate on the sustainability of blockchain. *Joule, 6*(6), 1137-1141.

Sedlmeir, J., Buhl, H. U., Fridgen, G., & Keller, R. (2020). The energy consumption of blockchain technology: beyond myth. *Business & Information Systems Engineering, 62*(6), 599-608.

TRONSCAN. (2022). TRON Node Distribution. Retrieved from https://tronscan.org/#/blockchain/nodes

U.S. Energy Information Administration. (2021). How much electricity does an American home use? Retrieved from https://www.eia.gov/tools/faqs/faq.php?id=97&t=3

Appendix A: Hardware Selection

We use the Passmark CPU Benchmark Dataset. Our methodology to select three CPUs consists of the following steps:

1) The data set contains many processor types that are not relevant to us. We filter out:

   A) CPUs with less than 50 benchmarking results, as we expect that they are not relevant for the validator community.

   B) CPUs that were released before 1/1/2015, as we consider less usage of outdated hardware and a practical reason: We cannot buy these CPUs in the market.

   C) CPUs with missing or incomplete data.

   D) CPUs of AMD. Intel is the dominating manufacturer of CPUs with over 80 % market share over the last years. Not all values in the data set are consistent between both producers, and already one AMD system is included in our data set. Therefore we decided not to consider AMD processors.

   E) CPUs intended for servers or notebooks. We think that the share of server hardware is low and notebooks nonexistent. Some CPUs are marked as "Laptop only" in our dataset; however, we find them included in MiniPCs, e.g., the Intel NUC. To account for these CPUs, we consulted geizhals.de as a source of CPU models sold within MiniPCs and did not remove them from the data set.

2) After obtaining a cleaned data set, we can separate the data set into three equally large categories for later selection: High-level, mid-level, and low-level. While the hardware within the networks might not be equally distributed among these three categories, this approach allows us to shift the allocation for single networks between the devices depending on their hardware requirements.

3) We are confronted with the fact that older, high-level CPU models might have the same computational power as recent low-level CPU models but different energy efficiencies, leading to entirely different results. Therefore, we introduce an additional variable in our data set called *energy efficiency*. The energy efficiency of a processor is the average benchmarking result divided by the TDP. The TDP serves as a proxy for a processor's energy demand capabilities, as it describes the maximum amount of heat measured in Watts the CPU cooling system has to deal with.

4) This variable allows us to calculate the average energy efficiency for each category of CPUs (4-high/3-mid/2-low) and select an average processor from the respective tier. This approach ensures that we a) cover three different performance categories and b) select an average energy efficiency for their respective class.

Appendix B: Electricity Measurements of Single Nodes for TRON network

All electricity measurements are conducted in Watt.

	1	2	3	4	5	6
Min [W]	N/A	N/A	N/A	13.76	28.41	118.83
Q1 [W]	N/A	N/A	N/A	14.92	29.18	121.07
Mean [W]	N/A	N/A	N/A	16.79	31.18	123.45
Median [W]	N/A	N/A	N/A	15.81	29.65	122.19
Q3 [W]	N/A	N/A	N/A	16.71	30.3	123.68
Max [W]	N/A	N/A	N/A	36.89	53.67	179.17

Table 13: Electrical power while running a TRON full node measured in Watt [W]

Appendix C: Data sources for TRON network

Market capitalization is taken from https://coinmarketcap.com.

TRON	Information
Measurement period	2022-06-30 21:31:49 to 2022-07-01 21:31:49
Number of nodes	https://tronscan.org/#/sr/representatives => "*Super Representatives*"
Transaction Count	Transaction count taken from Node API (https://tronprotocol.github.io/documentation-en/api/http/)
Software version	*GreatVoyage-v4.4.6(David)* (https://github.com/tronprotocol/java-tron/releases/tag/GreatVoyage-v4.4.6)

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.

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