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Update Report

The Energy Efficiency
and Carbon Footprint of the

Polygon Blockchain

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

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Preamble

This commissioned report is prepared by CCRI for
Polygon Technology

Executive summary

- CCRI **published a report** in September 2022 on the electricity consumption and carbon footprint of the Polygon network, **covering emissions** from both layer 2 and the underlying layer 1, Ethereum.
- **The Merge**, Ethereum's switch from Proof of Work (PoW) to Proof of Stake (PoS), has **significantly reduced the network's electricity consumption and carbon footprint.** This also reduces the **Polygon layer 1 emission allocation**.
- **This update report** covers:
    - Polygon's **remaining emissions "pre-Merge",** from 1st August 2022 till 15th September 2022 (till the Merge), that were not subject to the previous report and
    - **Polygon's updated layer 1 allocation emissions "post-Merge"** as well as a comparison to the initial indication provided in the previous report.
- From 1st August 2022 till 15th September 2022, it is estimated that the **activity of Polygon on Ethereum** (pre-Merge) has **caused 4.0 $ktCO_2e$** emissions. Since the inception of the network, Polygon has caused **98.7 $ktCO_2e$** on the Ethereum PoW chain.
- As the majority (more than 99.9 %) of emissions originated from the activities of Polygon on Ethereum with PoW, the **Merge also has reduced the overall carbon footprint** of the Polygon network **by 99.91 %.** Now, only 8.85 % of the total network emissions result from the layer 1 allocation.

I. Overview

In September 2022, CCRI published an extensive report on the electricity consumption and carbon footprint of the Polygon network, including both emissions from Polygon's own PoS network as well as emissions that are a result of activity on Polygon's layer 1 network, Ethereum. As Ethereum has leveraged the PoW consensus mechanism, the associated emissions of these activities by the Polygon network resulted in significant emissions, making up more than 99% of Polygon's total emissions.

The long-awaited Merge, Ethereum's switch from Proof of Work to Proof of Stake, has considerably reduced the electricity consumption and carbon footprint of the Ethereum network: The electricity consumption has been reduced by over **99.988 %** and the carbon footprint by over **99.992 % (CCRI, 2022f)**. This reduction corresponds to shrinking the Eiffel tower to the size of a plastic toy figure.

While the Merge has reduced the environmental impact of the Ethereum network, it also has a positive effect on any layer 2 application, side chain or rollup network that builds upon Ethereum. This also applies to Polygon. While CCRI predicted the Merge's effect on Polygon's environmental sustainability metrics, this report updates and refines this estimate.

Additionally, this report includes a calculation for the remainder of the emissions of Polygon's activity on the PoW Ethereum network from 1st August 2022 till 15th September 2022. This enables to calculate the entire carbon footprint of the Polygon network for the "Ethereum PoW" period.

Author's note:

This report is an update to the report "**Energy Efficiency and Carbon Footprint of the Polygon Blockchain"**, published by CCRI in September 2022, commissioned by Polygon Technology. The report is available here. For the sake of brevity, this report **does not** reiterate the approach, methodologies, and assumptions made in the previous report. If you are interested in understanding the underlying mechanisms of the calculations, we recommend reading the initial report first and then continue reading this update.

Thanks,
CCRI team

II. Remaining Emissions from PoW allocation

The previous report provided an extensive overview and reasoning for determining the carbon footprint allocation from the base layer, Ethereum, to the Polygon network. This chapter gives a brief overview of the process and then provides the updated results.

1. Base layer allocation of Ethereum PoW

Polygon is a layer 2 Proof of Stake network built on the Ethereum network which utilized a Proof of Work consensus mechanism until 15th September 2022 and then switched to a PoS algorithm. Polygon relies and utilizes Ethereum's security properties for the integrity of its own network by periodically committing the state of its own chain on Ethereum. To conduct a proper emission estimate of the Polygon PoS network, one also needs to account for any activities that the Polygon network is responsible for on the underlying Ethereum layer. For that, we deploy a five-step approach as outlined in our previous report to understand and calculate the CO_2e emissions stemming from the activities on the Ethereum base layer (CCRI, 2022d).

We leverage the methodology for deriving the **electricity consumption** of Ethereum by Gallersdörfer, Klaaßen, and Stoll (2020) and the **carbon intensity** of Proof of Work networks by de Vries, Gallersdörfer, Klaaßen, and Stoll (2022)[1]. We use a **hybrid allocation methodology** to account for both transactions and holdings as outlined in (CCRI, 2022a)[2]. We **identify Polygon's smart contract addresses** using Etherscan (2022) and **export transaction and holding data** using Trueblocks (2022).

2. Emission allocation results

The respective 39 contracts are involved both in transaction activity as well as in holding cryptocurrency. Table 1 summarizes the results for both activities over the period between the last report and Ethereum's merge as well as the total network lifetime of Polygon on Ethereum with Proof of Work.

Period	Emissions from transactions	Emissions from holdings	Total emissions
(1) Remaining period (01.08.2022 – 15.09.2022)	536.27 tCO_2e	3,439.19 tCO_2e	3,975.46 tCO_2e
(2) Total (20.04.2019 – 15.09.2022)	42,140.53 tCO_2e	56,527.70 tCO_2e	98,668.23 tCO_2e

Table 1: Overview of the base layer allocation emissions for both holdings and transactions for (1) the remaining period and (2) the total network lifetime on Ethereum PoW.

We find that the Polygon network is responsible for 4.0 kt CO_2e emissions due to its activity on the base layer of Ethereum for the remaining period since our initial report. In total, Polygon's entire emissions as of its base layer allocation of Ethereum's Proof of Work **amounts to 98.7 kt of CO_2e emissions**.

[1] Transparency notice: These two papers were co-authored by the founders of CCRI.
[2] Transparency notice: The hybrid approach was developed by CCRI and South Pole under consultation with PayPal (CCRI, 2022a). A more technical whitepaper is also available (Gallersdörfer, Klaaßen, & Stoll, 2021).

III. Impact of the Merge on Polygon's environmental sustainability

1. Influence of the Ethereum Merge on the Polygon network emissions

In our initial report, we estimated the CO_2e emission allocation for Polygon on the pre-Merge Ethereum network to be 60,903 tonnes CO_2e from 01st August 2021 to 31st July 2022 (CCRI, 2022d). We furthermore approximated the emissions of Polygon's PoS network to be 50.13 tonnes CO_2e for the same period. Thus, we concluded that most of Polygon's emissions (99.92 %) are due to activities on the base layer network Ethereum.

Given that Ethereum has switched from Proof of Work to Proof of Stake on 15th September 2022, an event, which is referred to as "The Merge", the electricity consumption and thus the carbon footprint of the Ethereum network has been reduced significantly. CCRI has analyzed the impact of Ethereum's Merge and provided results on the electricity consumption and carbon footprint of the post-Merge network (CCRI, 2022f). Our calculations take the client diversity within the Ethereum network into account and develop a best guess estimate for the electricity consumption of an average node participating in the network. Table 2 summarizes the estimates for Ethereum PoW before and Ethereum PoS after the Merge.

	Ethereum PoW	Ethereum PoS	Reduction
Electricity consumption [MWh/year]	22,900,320	2,600.86	99.988 %
CO_2e emissions [t/year]	11,016,000	869.78	99.992 %

Table 2: Comparison of annualized electricity consumption and CO_2e emissions of the Ethereum network before (PoW) and after (PoS) the Merge

We found that the annualized electricity consumption of Ethereum is reduced by 99.988 %, corresponding to a reduction factor of over 8,639. Similarly, Ethereum's CO_2e emissions are reduced by a factor of over 12,425 (99.992 %). As a result, the emissions Polygon causes on its base layer Ethereum are likewise reduced substantially: Applying the reduction factor we have determined, Polygon's activities on the post-Merge Ethereum base layer amount to **4.87 tonnes CO_2e**. Table 3 summarizes the influence of Ethereum's Merge on the carbon footprint of the Polygon layer-2 network.

	pre-Merge	post-Merge
CO_2e emissions layer 1 allocation [t/year] (overall share)	60,903 (99.92 %)	4.87 (8.85 %)
CO_2e emissions layer 2 PoS network [t/year] (overall share)	50.13 (0.08 %)	50.13 (91.15 %)
CO_2e emissions Polygon total [t/year]	60,953.13	55.00

Table 3: Comparison of annualized carbon footprint of the Polygon network before and after the Merge of the Ethereum base layer

We find that the share of Polygon's emissions from its base layer activities is reduced from 99.92 % to 8.85 % because of Ethereum's drop in electricity consumption and carbon footprint. In total, the annualized emissions of the Polygon network after the Ethereum Merge amount to 55 tonnes CO_2e.

2. Comparison of Polygon "Post-Merge" network to other PoS systems

In the following, we contextualize our updated results for the Polygon network emissions after the Merge to other PoS systems. We also put the electricity consumption in context; for that, we leverage the carbon intensity of 501 gCO_2e/kWh as established in CCRI (2022d). We point out that comparing different Proof of Stake networks is challenging: Different network sizes, transaction throughputs, and other capabilities such as layer 2 networks or sidechains might add to the electricity consumption and carbon footprint of the respective network.

Yearly electricity consumption in the context of other systems

In our previous report, we outlined that the yearly electricity consumption of the Polygon PoS network amounts to roughly 109,213 kWh (CCRI, 2022d). The updated base layer allocation after Ethereum's Merge adds further 9,720.56 kWh. An average US household consumes about 10,600 kWh per year and, therefore, the Polygon PoS network consumes about 10.3 times the electricity, and the base layer allocation of Ethereum adds slightly less than one further household (U.S. Energy Information Administration, 2021).

In comparison to the decentralized cryptocurrency Bitcoin, the Polygon PoS network consumes only about 0.00011 % of the Bitcoin network assuming 97.11 TWh on 15th September 2022 (CCRI, 2022b). 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 1, we compare the Bitcoin network, the Ethereum for both pre-Merge (assuming 21.99 TWh on the 14th September 2022 (CCRI, 2022b)) and post-Merge (assuming 0.0021 TWh on the 15th September 2022 (CCRI, 2022b, 2022f)), TRON (CCRI, 2022e), and further PoS networks we have analyzed in CCRI (2022c). For these additional networks, we use updated values from our API (CCRI, 2022b). For comparison, we add an average US household to the figure. Note that the networks drawn in gray are limited in their comparability given the age of the analysis (conducted from August to October 2021).

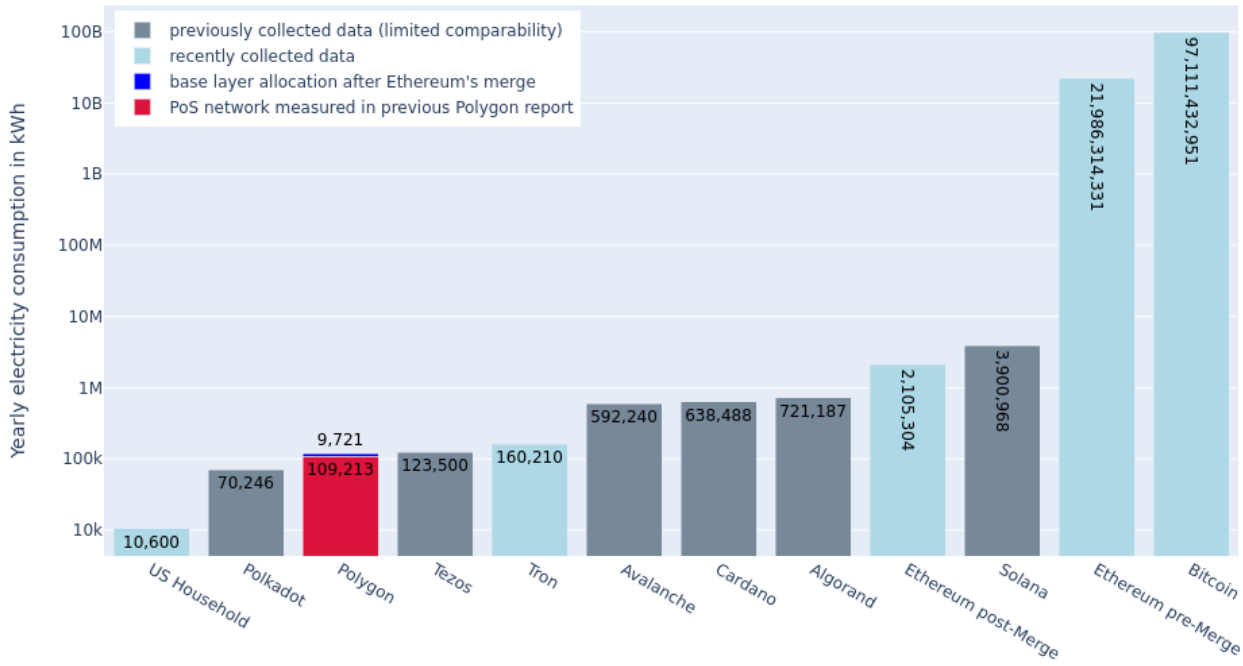

Figure 1: Yearly electricity consumption Polygon, Bitcoin, Ethereum pre- and post-Merge, Proof of Stake networks TRON, Polkadot, Tezos, Avalanche, Algorand, Cardano, and Solana, and an average US household in kWh. Logarithmic scale.

Carbon footprint in the context of other systems

Overall, the emissions of PoS networks are very low. As calculated in (CCRI, 2022d), the Polygon PoS network emits 50.13 tons of CO_2e yearly. For example, 8 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 PoS network of Polygon. Polygon is responsible for further 4.87 tonnes of CO_2e on its base layer Ethereum after the Merge. This allocation on the post-Merge Ethereum base layer is slightly less than an additional round trip. It can be assumed that the CO_2e emissions of companies behind the networks are higher than the emissions from the network itself.

Figure 2 compares the carbon footprints of Polygon, Ethereum post-Merge further PoS networks from our previous research (CCRI, 2022b, 2022c, 2022e, 2022f) and to a roundtrip MUC – SFO in business class. Again, the gray-colored networks are only comparable to a limited extent due to the age of the analysis.

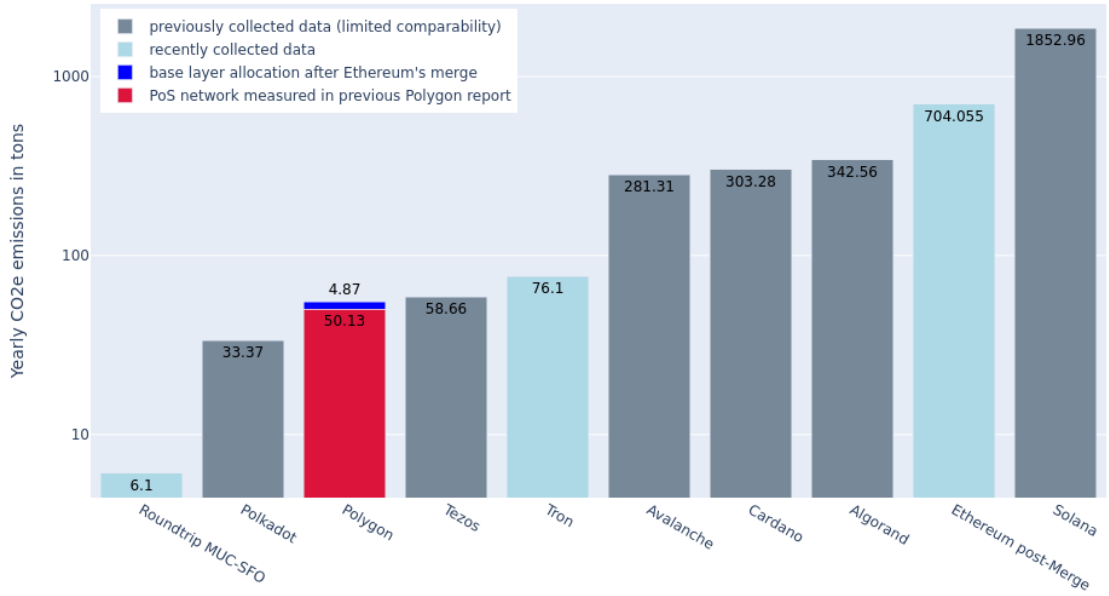

Figure 2: Yearly carbon footprint of Polygon compared to other PoS networks and to a roundtrip flight in business class

Assessment of the previous report's estimates

Overall, we find that the first indication in the initial report "Energy Efficiency and Carbon Footprint of the Polygon Blockchain" (CCRI, 2022d) overestimates the emissions of the Ethereum layer 1 post-Merge by about 20 %, resulting in a lower carbon footprint of the Polygon network post-Merge than initially anticipated. We reduced our estimates for the allocated electricity consumption from 12,166 kWh to 9,721 kWh and the allocated carbon footprint from 6.09 to 4.87 tonnes CO_2e.

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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.