Blockchain Carbon Emission Calculator Methodology

**Overview**

Below is Return Protocol’s blockchain carbon footprint calculator. Return Protocol estimates the carbon intensity of Ethereum, Bitcoin, and many Proof of Stake (PoS) blockchains. In theory understanding the carbon intensity of blockchains is relatively straightforward; however, in practice the accuracy and robustness of each calculation is muddied by the availability and quality of necessary information. While Return Protocol does its best to calculate the carbon footprint of each user, the precision of each calculation will vary depending on the chain.

The methodology below outlines the information needed to calculate a blockchain’s carbon footprint, along with the necessary assumptions made where information was poor or unavailable. It also examines the relevant challenges and steps taken with respect to Ethereum, Bitcoin, and other PoS chains. As the Web3 space evolves and more data becomes available, these calculators will be updated with the most accurate and up-to-date information.

**Necessary Information**

* Geography of Validators.
* Carbon Intensity of Each Geography (Grid Emission Factors).
* Recommended System Requirements of Validators.
* Average Energy Use of Recommended System.
* Percentage of Hash Rate/Usage per Geography.
* List of Total Historical Transactions on Blockchain.

**Necessary Assumptions**

* The carbon intensity in each region is correct – some regions may have poor data.
* We assume that validators are getting electricity from the grid.
* Each validator consumes the same amount of energy on average and uses the recommended system requirements.
* People are not using VPNs to hide their location.

**Calculation for Carbon Intensity per Transaction (Yearly)**

1. Weighed Regional Carbon Emissions (tCO2e)

* Equation:
* N = Number of Active Validators in Region on a Given Day
* Sr = Estimated Average Electricity Consumption of Validators per Day (MWh)
* Ci = Carbon Intensity Factor of Region (Grid Emission Factor)
* U = Percent of Mining Occurring in Region Relative to Other Regions

1. Total Blockchain Carbon Emissions (tCO2e) on any Given Day

* Equation:
* Ri = Region i
* Rn = Last Region

1. Average Carbon Emissions per Transaction (tCO2e)

* Equation:

1. Estimate Individual Carbon Footprint (tCO2e)

* Equation:
* NT = Number of Individual Transactions
* d = First Day
* d + i = All Other Days

**How to Improve Accuracy**

* Understand what percentage of validators use VPNs and work to find out where they are.
* Update any/all relevant information on a daily, weekly, monthly, quarterly basis – the shorter the interval the more accurate the results.
* Run a node with different system requirements to understand electricity consumption.
* Where possible, reduce size of region to get a more precise understanding of carbon intensity or energy consumption.
* Contact validators to understand exact energy consumption.
* Contact validators to understand used systems.

**Summary**

The carbon footprint of each blockchain is calculated using the methodology listed above; however, each chain has its own unique challenges and characteristics which may impact the accuracy of the final calculation. Below, are summary overviews of how Ethereum, Bitcoin, and other PoS chains are calculated.

**Ethereum (Proof of Work)**

Return Protocol calculates Ethereum’s carbon footprint using a bottom-up approach. This is achieved in three parts (see excel doc here):

Energy Consumption: To calculate total energy consumption, Return Protocol leans on user-reported GPU hash rate and power draw data.[[1](https://minermonitoring.com/benchmark)][[2](https://www.tomshardware.com/best-picks/best-mining-gpus-benchmarked-and-ranked)] Return Protocol then uses information from [Hive OS](https://hiveon.com/statistics/) to understand which GPUs were most popular to compute a weighted average hash rate and power draw. Lastly, [four other](https://arxiv.org/pdf/2112.01238.pdf) relevant factors (power supply efficiency, hardware overhead, datacenter overhead, and grid loss) are applied to compute a final value for each year since 2015. To calculate the daily energy consumption of the Ethereum blockchain the [daily hash rate](https://etherscan.io/charts) is divided by the estimated average GPU hash rate. The result gives an estimate for the total number of GPUs needed to create Ethereum’s daily hash. That figure is multiplied by estimated GPU power draw to calculate Ethereum’s estimated daily energy consumption (MWh).

Grid Emission Factors: The Ethereum Blockchain relies on a global community of validators. To calculate Ethereum’s carbon intensity, the Grid Emission Factor (GEFs) of each country/region where Ethereum is mined are needed. These factors are subject to their own imperfections – while developed economies like the United States provide reasonably up to date GEFs, nations with less robust economies may provide little to no information at all. Additionally, some nations may provide misleading or inaccurate GEFs. For this reason, Return Protocol only uses GEFs provided by trustworthy institutions[[1](https://www.eia.gov/state/rankings/#/series/51)][[2](https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-explore.html)][[3](https://www.carbonfootprint.com/docs/2022_01_emissions_factors_sources_for_2021_electricity_v10.pdf)] or the [UNFCCC](https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-07-v5.0.pdf). Lastly, many nations did not start calculating GEFs until relatively recently. Unfortunately, this forces Return Protocol to make some assumptions about historical GEFs that may impact accuracy.

* Node Geolocation: While many websites show daily, or weekly node geolocation data, very few store historical information. To overcome this, Return Protocol uses the [Wayback Machine](https://web.archive.org/web/20220000000000*/https:/etherscan.io/nodetracker) to search Etherscan.com’s [Node Tracker](https://etherscan.io/nodetracker), which provides updated daily heat maps of validator locations. Etherscan.com has data going back to late 2018. For all previous years Return Protocol applies the same GEF mix as the oldest date.
* GEF Weighted Average: A weighted average GEF is calculated from the daily snapshot of validator geolocations. This final value is multiplied by the estimated daily energy consumption to get an estimated daily carbon intensity (tCO2e) of the Ethereum blockchain.

Emission per Transaction: Finally, estimated daily carbon emissions are divided by the total transactions on each equivalent day. The product represents the estimated carbon intensity per transaction per day (Tx/tCO2e). To calculate a user’s individual on-chain carbon footprint, the Tx/tCO2e is multiplied by the quantity of transactions the user made on the equivalent day. The process repeats for all days the user made transactions on the Ethereum Blockchain. The products are summed to calculate the user’s total lifetime carbon footprint.

Note: Post-merge, Ethereum will become a PoS chain – all transactions occurring post-merge will be calculated using the PoS methodology.

**Bitcoin**

Return Protocol calculates Bitcoin’s carbon footprint using a bottom-up approach. This is achieved in three parts (see excel doc here):

Energy Consumption: To calculate total energy consumption, Return Protocol estimates the average yearly TH/s and Power Draw (W/h) of ASIC Miners since 2014. The information is calculated using data from data.hashrateindex.com which provides a [graph](https://data.hashrateindex.com/chart/history-of-asics) of historically popular ASIC Miners. The mining efficiency of equipment used prior to 2014 is estimated using information provided by [Foundry](https://foundrydigital.com/btc-mining-101.pdf). These values are then divided by the daily hash rate to approximate the total number of miners on any given day. The subsequent values are multiplied by average daily Power Draw to find an estimated daily power draw (MWh).

Miner Geolocation: Bitcoin relies on a global community of miners to validate each Bitcoin transaction. To calculate Bitcoin’s carbon intensity, the Grid Emission Factor (GEFs) of each country/region where Bitcoin is mined are needed (see Ethereum methodology). Unfortunately, due to Bitcoin’s culture of privacy, many miners choose to obfuscate their location by using VPNs. This complicates finding an accurate weighted GEF mix. Return Protocol leans on research conducted by [University of Cambridge](https://ccaf.io/cbeci/mining_map) which provides miner geolocation data from 2019-2021. This data set is used to forecast the GEF mix for 2022 and all years prior to 2019. To account for less efficient/sustainable energy grids, an inefficiency factor is applied (1.875 percent each year). These values are multiplied by estimated daily power consumption to produce an estimated daily value for carbon intensity (tCO2e).

Emission per Transaction: Finally, estimated daily carbon emissions are divided by the total transactions on each equivalent day. The product represents the estimated carbon intensity per transaction per day (Tx/tCO2e). To calculate a user’s individual on-chain carbon footprint, the Tx/tCO2e is multiplied by the quantity of transactions the user made on the equivalent day. The process repeats for all days the user made transactions on the Ethereum Blockchain. The products are summed to calculate the user’s total lifetime carbon footprint.

**Proof of Stake Chains**

PoS chains (including Ethereum post-merge) are also calculated using a bottom-up approach (see excel doc here):

Energy Consumption: Each PoS chain lists validator node requirements – both minimum and recommended. Return Protocol finds the estimated average power draw of the recommended system, the number of validators currently (and historically) in use and multiplies these factors together to produce the average estimated daily power draw of the blockchain.

Node Geolocation: Unlike Ethereum and Bitcoin, many PoS blockchains do not track, provide, or store historical node geolocation data (although some do). This decision may be due to privacy concerns, a lack of decentralization, or may simply not be a priority for the development team. In any case, Return Protocol uses any information that is readily available to determine which GEFs apply.

Emission per Transaction: Just like with Bitcoin and Ethereum, the estimated daily carbon emissions are divided by the total transactions that have occurred on the equivalent day. The result represents estimated carbon intensity per transaction (Tx/tCO2e). To calculate a user’s individual on-chain carbon footprint, the Tx/tCO2e is multiplied by the quantity of transactions the user made on the equivalent day. The process repeats for all days the user made transactions on the relevant blockchain. The products are summed to calculate the user’s total lifetime carbon footprint.

Note: There is a massive difference in energy/carbon intensity between PoS chains and PoW chains. A user who exclusively transacts on PoW chains will have a carbon footprint measured in tons or kilograms, while someone who only uses PoS chains will measure their emissions in grams.