Carbon.FYI Methodology

👀 If you haven't seen carbon.fyi yet, check it out! It's an emissions calculator for the Ethereum blockchain.

This page summarizes Offsetra's rationale and methodology for the calculation of CO2e emissions from the Ethereum network. This methodology is behind the Carbon.FYI calculator.

We initially published this work on September 28th 2020, it has since been cited by others in the community. We ask that if you do use our assumptions and approach, or iterate on this work, that you please cite us and reference the data source.

In the case that you can improve our assumptions with more up-to-date data, we welcome the feedback! By working on these issues collaboratively, and helping to inform the community on the impacts and some of the solutions for crypto CO2-equivalent (CO2e) emissions, we can make a pretty big difference.

You can view the tabulated data and calculations here.

Update log

- **24th Jan 2021:** Updated total power utilised on the Ethereum network for 2020, yielding an increase of ~900MWh
- **8th March 2021:** Removed the 20% buffer that was previously considered potential losses through transmission and distribution (within the power system) and inefficiencies at the point of use (i.e. from heat). Also updated grid emissions intensity for China (see sources spreadsheet). Note, both of these changes altered our emissions per unit of gas.

- **20th March 2021:** Updated the total gas usage and transaction count data to be congruent with the 2020 energy data utilized. Emissions per unit of gas were modelled across three energy usage scenarios.

The Formula

Check out the spreadsheet itself for sources and data points, but below is presented the brief methodology that we followed to find the emissions per transaction on the Ethereum network.

i = country *(see country emissions factor tab on the spreadsheet for full list of included countries)*

t = total power consumption of Ethereum network (TWh)

p_i = proportion of total hash

c_i = national power consumption for Eth mining (TWh)

$$t * p_i = c_i$$

b_i = national grid emission intensity (CO2e/TWh)

e = total emissions from eth network (CO2e)

$$\sum_{i=1}^{n} b_i \times c_i = e$$

x = total transactions on Ethereum network in a given year

CARBON.FYI = emissions per transaction on the Ethereum network

$$CARBON.FYI = x/e$$

The Problem

The Blockchain is a distributed ledger, which contains a record of all transactions, arranged in sequential blocks. The distributed nature means that users cannot spend any holdings twice or manipulate the Blockchain for gain.

The way that manipulation is detected and rejected is through the 'Proof of Work' consensus mechanism that requires network participants (*miners*) to undertake complex search problems. To add a valid block to the Blockchain, miners use specialized software to solve the problems and are then issued a certain number of Ethereum in return.

Over time, the complexity of these problems has increased in response to more miners, with more advanced hardware. As the frequency of mining has increased, the electricity expended to mine cryptocurrencies has too.

Given the electrical load required to undertake Proof of Work, and the frequency of cryptocurrency transactions, the energy demand from this activity is significant. This mining is therefore responsible for the greenhouse gas emissions proportional to the power used, considering the respective national emissions intensity of the power system.

The annual power consumption from Ethereum activity is estimated to be 9.06TWh for the year of 2020. For Bitcoin, its 7-times that 68.33 TWh. For reference, Chile used around 73TWh of power in 2019-20. Note, three energy usage scenarios were modelled using aggregated data across a number of sources, yielding the following:

Low: 5.65 TWh

Average: 9.03 TWh

High: 19.44 TWh

Hash rates and computing power

To calculate the emissions of the Ethereum network Offsetra first analyzed the network of miners which are powering the network and their corresponding hash rate.

The hash rate of each mining pool is assigned to a geography based on the data available on mining pool registrations (see source 2), mining pool locations were used as a proxy to determine the emissions intensity of each mining pool's power usage. The ratio of hash rate to country's mining pool was utilized to distribute the total network consumption across countries.

Once this was completed, we used the electricity grid emissions coefficients for each geography to determine the total carbon emissions from each pool, and thus the network as a whole.

Mining Pools & Geographic Attribution

Mining pools are collective organizations composed of individual miners, each contributing their hashing power toward maintaining the network. An important caveat to our approach is that mining pools are distributed, and thus it's not with complete certainty that their entire hashing power can be attributed to the geography for which they are registered. One possible solution would be to take a global average of electricity grid emissions coefficients; however we felt the additional nuance would be beneficial to our transaction calculations and provide a framework for integrating more accurate data in the future.

Transactions

When a transaction is processed in Ethereum, a certain number of gas units are required according to the amount of computational resources required to complete it. Using this data, we can derive the average CO2e emissions per unit of gas across the three aforementioned scenarios:

Low: 0.0001132972855 kgCO2e

Average: 0.0001809589427 kgCO2e

High: 0.0003895583921 kgCO2e

This most recent data represents a 37% reduction in what was modelled using 2019 data. Our current understanding is that due to a greater amount of blockspace being utilized for transactions (and a general increase in the total number of transactions the network is processing), the 'per transaction' and 'per unit of gas' emissions have decreased relative to their share of the networks total emissions.

However, you should be aware that these numbers do *not model nor predict* the complex forces which drive future mining power and future emissions. Rather, it represents a fair, comparable and proportional share of emissions.

When a transaction is processed in Ethereum there are two core variables that those active in the space will be familiar with. The first is the gas limit, i.e., the 'size of the gas tank' required to run a transaction, as well as the gas price, i.e., what one is willing to pay for each unit of gas in the gas tank. Gas price (Gwei) can be thought of as what one is willing to pay miners in order to move up or down the line of transactions - e.g. paying a higher price will place your transaction before others that have paid a lower price. In relation to computation resources, the number of gas units within the 'gas tank' of the transaction is thus a proxy for the estimated effort required for a transaction.

Sometimes it's hard to predict how many units of gas a transaction will cost, so the actual cost of the transaction is computed afterwards. Initiators of transactions are charged for the used Gas and the difference is returned to the sender. Thus, when applying our emissions factor per unit of gas, we are applying it to the gas utilized by a transaction, and not just their gas limits.

Given the amount of gas used for certain complex Ethereum transactions, this value may yield 241kg CO2e for borrowing USDC on the popular Aave platform (considering a gas limit of 774000).

Alternatively, when looking at the total number of transactions in a given year, along with the relative network emissions data, the average emissions per transaction can be calculated. For 2019, our team calculated a value of approximately 19 kilograms of CO2e per transaction. When calculating the emissions of specific wallets, it's key to note that calculating emissions on a per unit of gas basis yields more accurate figures.

So called 'Whales' moving large amounts of funds and completing a greater number of complex transactions while interacting with yield farming platforms undoubtedly contribute to a greater share of the Ethereum networks emissions than people utilizing it to simply send Ethereum between wallets.

Assumptions

The base of these calculations is reliant on our computation of CO2e for each unit of gas on the Ethereum network. All carbon accounting methodologies make certain assumptions which are necessary for attributing emissions-generating activities to processes and people/organizations.

We've listed a few critical assumptions below:

1. Electricity usage was attributed to specific geographies (mining pools and their associated hash rates). The resolution of this data is such that nearly 70% of hashing power must be attributed to a global average emissions coefficient. Offsetra has reached out to miners to understand this data better.
2. Grid electricity assumptions were scaled to national boundaries (this was aligned with the hash rate attribution resolution available to us but could be improved in the future).
3. CO2-equivalent values were utilized taking into account greenhouse gas potentials of various pollutants over a 100 year time horizon.

4. In the case of wallet analysis, only **sent** transactions are attributed to the user.
5. In the case of contract analysis, only **received** transactions are attributed to the contract.
6. Total gas utilized includes the reward paid to miners (we're actively looking at the best way to account for this and feedback is welcome).

Limitations

We recognise that the outputs of this work are only as good as the data that we can access. At the time of writing, we believe that the data we have used is the most accurate available for this purpose. However, we recognise that there are clear gaps. As referenced above, Offsetra have reached out to the mining pools to understand better their power demand. We also understand that we may have not included some large, privately owned mining pools within this work - publicly available data is sparse for these pools. In the case that the unrepresented mining pools are powered by renewable energy (such as the Enigma one linked above), then we can be confident that the additional load they contribute to the network will be marginal in terms of its CO2e impact. This remains a a gap in our methodology.

Additionally, we acknowledge that there are some counter arguments to our perspective of the carbon footprint of cryptocurrency. You can read more of these arguments from Coindesk and Coin Telegraph. We won't go into the nuances of this debate here, however the cornerstone rationale is:

1. Crypto miners are incentivised to work by low power prices.
2. Lower power prices are (arguably) a proxy for a lower CO2 intensity of power at a given point in time.
3. Hence, crypto miners must be using renewables only, and have little net negative carbon impact on the power system, energy system, or our depleted carbon budgets.

We won't go into this in great detail here, as the debate is a classic bit of micro-economic versus. macro-economic analysis. Numbers can be manipulated to achieve preferable outcomes for those on either side of the fence. However, a few qualitative points from us in response to this disagreement:

- All electrons are created equal - we can't tell if they are generated from renewables or by burning coal. Hence, we are best-placed to take the mass-balance approach when looking at system flows of energy, electricity or carbon. This is how national governments look at and account for their emissions, it is how those who have to pay a carbon tax on their consumption are evaluated, and we believe it is the most accurate and reasonable way to account for the impact that a single point of energy demand has on its national system.
- All users of energy are the same: they want it cheap. Cryptocurrency miners **are not unique** in any way, shape or form. It is always a race to the bottom for users: whether its the droves of users of new electric vehicles utilising smart charging; or whether its huge consumers in the mining, refining or chemical industries. This race to the bottom is why power prices are highly dynamic and no entity is hugely effective in beating the market.
- In any case, **price does not determine the CO2 emissions of electricity** (China has a real appetite for cheap power, and its fulfilling this with brand new coal power plants).
- Indeed, in some cases a large point source of power demand may be able to provide 'Demand Side' services to the power system, this is a price-driven response (rather than a carbon-driven response). This may be a fair proxy for net positive [economic] effect that a large load can have on the grid when managed well. We have not seen any evidence that crypto miners are providing Demand Side Response yet.
- Therefore, unless a load generating asset has a private wire connection to a renewable energy source, it should take the national average (mass balance) of emissions per kWh of electricity consumed for its activity. It is 'fair' to consider cryptocurrency mining in line with all other loads on the network, as opposed to a special element of power demand that deserves less scrutiny or attention *(because, why would it?)*.
- Fundamentally, to avoid unmitigated climate collapse, we need to **reduce** our power demand, not increase it. Until we reach the point when we can be confident that global power emissions are zero (***not*** net-zero), we must avoid adding load to the system. Where it emissions are unavoidable, Offsetra's position is that we must begin to compensate.

- Bitcoin and Ethereum contribute to around 75TWh per year to the world's power demand; that is a significant number and comparable to the consumption of a moderately sized national economy.

Conclusion and future work

By using existing and available data, we have concluded that the average emissions per Ethereum transaction is 18.05kgCO2e**.** This value is considered the most reasonable assumption that can be made available on the publicly available data for 2020.

Furthermore, to provide greater insight the impact of various transactions, our team calculated the emissions per unit of gas within an average energy scenario to be **0.0001809589427kg CO2e.**

We consider it our responsibility to examine and utilize the available data and provide solutions for the market. Thankfully, we are not alone in this effort, and there is a growing body of research investigating the environmental consequences of cryptocurrency usage. In particular, we would like to highlight the work of Alex de Vries in exploring the energy usage and greenhouse gas emissions of various blockchains.

If you've enjoyed reading this and you've learnt something, we ask you to consider offsetting your emissions with Offsetra at offsetra.com. Offsetting with us enables us to continue working on these issues, publishing our work and developing solutions with the community.

If you're already set up with crypto, why not check out a couple of our other projects in the space with Confluence Analytics or Spendless.

Reach out to us if you'd like to discuss our methodology or this work, we'd love to talk:

Email: info@offsetra.com

Twitter: twitter.com/offsetra