Measuring the Environmental Impact of Cryptocurrency

Introduction

Cryptocurrencies, and their underlying blockchain technology, are helping solve previously unsolvable problems for people and industries around the world. However, the industry lacks a common and clear definition to determine how sustainable cryptocurrencies are, nor is there a consensus methodology for calculating its impact on the planet.

The environmental ramifications of producing and circulating physical currency are shockingly profound. In theory, cryptocurrency is meant to avoid some of these consequences because these are digital assets, by design. However, depending on the specific cryptocurrency, the energy consumption required to produce it varies wildly. It's no secret that the largest cryptocurrencies require large amounts of energy consumption to power creation of new coins—and mining is at the core of the issue. But just how dire that impact is, remains unclear.

Ripple's Data team, along with external academics, worked to provide a clear and consistent methodology to set the industry standard. Together, the teams followed a bottom-up approach that leverages aspects of the Cambridge Bitcoin Electricity Consumption Index (CBECI) and the 2018 method proposed by Max J. Krause and Thabet Tolaymat. In defining environmental research around the digital asset XRP specifically, we worked with Watershed, a tech company that helps companies build climate programs, to measure the carbon footprint of the XRP Ledger. Additionally, Max J. Krause, provided an in-depth analysis and the summary within this methodology.

Cryptocurrencies and blockchain have the power to engender greater financial inclusion and economic growth. Yet, energy consumption is a critical side effect of this technology and the unsustainable mining practices used are massive barriers for larger adoption. Sustainability is one topic that needs to be addressed to help ensure a sustainable future for the planet and the global economy.

Type	Blockchain Asset			Cash	Network	Network
	Bitcoin	Ethereum	XRP	Paper money (US)	Visa	Mastercard
Latest Available Estimate of Electricity consumption per transaction (KWh)	700 (2020 YTD)	30 (2020 YTD)	0.0079 (2019)	0.044 (2018)	0.0008 (2018)	0.0006 (2018)

XRP

The XRP Ledger is powered by a network of peer-to-peer servers, with Ripple now running approximately 17% of the validators on Ripple's recommended Unique Nodes List (UNL). Ripple publishes this recommended list, but servers are free to choose validators as they see fit. Ripple has detailed data on the servers it operates, and some crawler data on activity of servers operated by others. We worked with Watershed, a technology company that helps companies measure and cut carbon emissions, to estimate the energy consumption and carbon emissions of the XRP Ledger, using details provided by Ripple on Ledger nodes.

Watershed made the following assumptions:

1. All servers are similar to the servers operated by Ripple. We've made maximally conservative estimates for total power consumption and carbon emissions.

2. Machine uptime: We used the crawler data to select the nodes that were up in a given month. If a node was visible at the start of the month, we assume it to have been up the whole month. We assumed that each node had its own machine.

3. Machine type: We use Ripple internal data to approximate what machine (e.g. which AWS instance) was used to run each node type. We assume each node was run with the matching machine type.

4. Location: If machine location is provided, we use that. If it's not, we use the Internet Protocol address (IP) of the machine to get an approximate location. For Ripple operated machines, we use the region of the cloud instance. We assume machines draw electricity from their regional utility grid.

Using these assumptions, we've calculated energy consumption and carbon emissions of the XRP Ledger:

1. Energy consumption (total electricity required to run the XRP Ledger)

    a. For each machine type, we:

    • Identify a Central Processing Unit (CPU) with specifications matching the specs of the instance, and estimate total power consumption for a server running that CPU.

    • Multiply by an estimate of Power Usage Effectiveness (PUE), using published numbers if provided by the cloud provider or estimates from this report if not.

    • We multiply this power consumption for each machine type by total uptime for that specific machine type to estimate power consumption for compute.

    b. We add energy consumption estimates for storage and networking drawn from the literature.

2. Operational carbon (emissions to produce electricity to run the XRP Ledger)

    a. We assume each machine runs on the electricity grid of the region in which it's located, and use published carbon intensities to translate energy consumption into carbon emissions.

3. Embodied carbon (emissions to produce servers used to run the XRP Ledger)

    a. We've pulled from Life Cycle Assessments (LCA's) of standard servers cited in this report, and amortized these carbon emissions over an estimated machine lifespan of four years.

Bitcoin

When a user initiates a Bitcoin transaction, it is processed in "blocks" and added to a public and immutable blockchain for record keeping. Miners with specialized computers compete to solve complex mathematical problems in order to verify and process these blocks. When a new block is generated, the "winning" miner is rewarded for their efforts in Bitcoin—and that's how new Bitcoins are produced.

The complexity of these mathematical equations are constantly increasing to keep block production and Bitcoins in circulation at a stable level. Typically, Bitcoin miners operate on mining "farms"—large clusters of specialized computers commonly known as application-specific integrated circuit (ASIC) mining rigs. Mining efficiency, measured in hashrate/second, varies by mining rig models and determines how likely a miner is to get paid.

Therefore, to estimate the total electricity consumption of the Bitcoin network, Ripple's data team based our approach on the bottom-up method, the Cambridge Bitcoin Electricity Consumption Index (CBECI) model by Cambridge Center for Alternative Finance—adapted from a method by Marc Bevand— that leverages mining hardware efficiency and specifications data. Similar to the CBECI model, we provide a lower bound, floor, and upper bound, ceiling, estimate.

The underlying idea of the CBECI model is that miners will run mining equipment as long as they are profitable in electricity terms. Profitable means that miners make more money from Bitcoin rewards than they spend running the equipment. All underpinning assumptions, except Assumption 3c, remain the same as the CBECI model.

The key difference is incorporating the cost of mining equipment. Rather than assuming that all miners use an equally-weighted basket of profitable mining hardware, we assume that, holding efficiency constant, miners prefer cheaper mining hardware over expensive ones.

On average, an ASIC miner costs $1,500—but a high-performing miner may cost up to $6,000. Without the ability to predict future network behavior and the longevity of mining profitability, Bitcoin miners likely prefer the most cost efficient hardware at time of purchase. We use the metric Efficiency to Fixed Cost Ratio to describe this relationship:

$$EFC_i = \frac{1}{\vartheta_i * FC_i}$$
$$with$$
$$\vartheta_i - energy\ efficiency\ of\ mining\ hardware\ i\ [J/h]$$
$$FC_i - acquisition\ cost\ of\ mining\ hardware\ i\ [USD]$$

Assumption 3c: Hardware types that are profitable in electricity terms are used with frequency proportional to the hardware's Efficiency to Fixed Cost Ratio. Comparing Ripple's weighted best-guess estimate to the CBECI estimate using market share weighting, the results are within a 5% difference on average.

Ethereum

For ASICs mining rigs, microchips are programmed to solve for a specific hashing algorithm for Bitcoin. Ethereum miners, on the other hand, use a different mining hardware, Graphics Processing Units (GPUs). GPUs are more flexible and can adapt to different coin mining algorithms. Consistent with the estimation methodology for Bitcoin, Ripple's data team took a bottom-up approach based on a method proposed by Max J. Krause and Thabet Tolaymat, with Ethereum mining hardware as a starting point.

Our model takes into account the following parameters:

Parameter	Description	Measure/Unit	Source
Network hashrate	Total number of hashes produced by miners	Gigahashes per second (GH/s)	Dynamic: etherscan.io
Mining equipment hashrate	Measures the maximum number of hashes per hour of a giving mining hardware type	Megahashes per second (MH/s)	Static: u.today/guides/crypto-mining
Mining equipment power efficiency	Measures the rate of energy transfer for a given mining hardware type	Watts (1 watt is equivalent to 1 Joule/s)	Static: u.today/guides/crypto-mining
Mining equipment manufacturer market share	Measures the proportion of the GPU market controlled by a given hardware manufacturer	N/A	Dynamic: estimated from multiple sources

A list of more than ten GPU models commonly used for Ethereum mining during 2018-2019 is compiled and used in this analysis.

Given the exact electricity consumption cannot be determined, we provide a lower- and upper- bound estimate based on assumptions about hardware work efficiency levels and hardware models used. Work efficiency levels reflect the machine's output versus power draw. A recent experiment by Jarred Walton shows that the list of GPU models used in this analysis have work efficiencies that range from 45.3% to 85.9% scaled to the best performing GPU model. Until further research, staying close to the 90% used in the original research by Krause is acceptable.

Lower bound
Assumption 1(a): all miners always run the most efficient hardware available.
Assumption 1(b): all mining equipment work efficiency level is 100%.

Upper bound
Assumption 2(a): all miners always run the least efficient hardware available.
Assumption 2(b): all mining equipment work efficiency level is 80%.
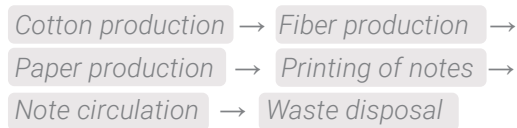
Best guess
Assumption 3(a): hardware brands are used with frequency proportional to the hardware manufacturer's market share.
Assumption 3(b): among available hardwares produced by the same manufacturer/brand, miners use an equally-weighted basket of hardware models.
Assumption 4: all mining equipment work efficiency level is 90%

Paper Money

The life cycle of paper money versus digital money is arguably much more complex and untraceable. Processes vary based on region and materials, but can roughly be mapped to:

Cotton production → Fiber production → Paper production → Printing of notes → Note circulation → Waste disposal

The industry has limited ability to collect accurate electricity consumption data for each step, so Ripple's preferred methodology focuses on printing of notes and note circulation. A study by S. Rochemont shows that ATM energy consumption is a dominant contributor to paper money energy impact.

Printing of Notes

Assumption 1a: 3% of printing cost contributes to electricity bills, consistent across note denominations.

Assumption 1b: The average electricity cost for the Bureau of Engraving and Printing bill manufacturer is consistent over time, and corresponds to 11.38 cents/KWh (the average 2018 household electricity unit cost in Texas, where the factory is located).

$$EC_m = \frac{C_m * Frac_{el}}{P_{el}} * OS_m$$
$$with$$
$$EC_m - \text{energy consumption of printing denomination } m \ [KWh]$$
$$C_m - \text{printing cost of denomination } m \ [USD], \ OS_m - \text{order size of denomination } m$$
$$Frac_{el} - 3\%, \ P_{el} - 0.1138 \ USD/KWh$$

ATM

A 2002 study by Roth et al. estimates that 0.84 Terawatt hours (TWh) was consumed by ATMs in the United States annually.

Assumption 2: ATM energy efficiency in 2018 was the same as in 2002.

Because a large source of electricity consumption for ATMs is air-conditioning, not included, the Roth estimate is likely lower than reality and may offset energy efficiency improvements in ATMs between 2002 and 2018.

Paper Money Transactions

Total paper money transactions are based on the U.S. census population data and average number of cash transactions per person per month, as estimated by the Federal Reserve in 2018.

The environmental cost of paper money has far greater scope beyond electricity consumption. Paper production, printing and waste disposal are known to contribute to eutrophication, global warming, photochemical ozone creation and human toxicity. The transportation of paper money leads to greenhouse gas emissions. Physical banks and chest branches that serve as paper money vaults also consume significant electricity from computers, lights, heating and cooling.

Visa, Mastercard

Estimates for both Visa and Mastercard networks leverage a top-down approach. Until recently announcing reaching 100% renewable energy goals, both networks published official reports of the business' electricity consumption and data center specific consumption for 2017-2019.

Visa and Mastercard data centers perform all transactions related computation. Dividing data center electricity consumption by number of switched transactions, we can estimate electricity consumption per transaction. Comparing the estimate for Visa and Mastercard, the results are very close.

You can view all research and associated analysis here.

About Ripple

Ripple provides one frictionless experience to send money globally using the power of blockchain technology.

By joining Ripple's growing global network, RippleNet, financial institutions can process their customers' payments anywhere in the world instantly, reliably and cost- effectively.

Banks and payment providers can leverage the digital asset XRP through our On-Demand Liquidity service to further reduce costs and access new markets.

Join the Conversation

twitter.com/ripple
linkedin.com/company/ripple-labs
ripple.com/insights
facebook.com/ripplepay

Contact Us

For more information about how RippleNet's On-Demand Liquidity service can be leveraged as an alternative to pre-funding to process global payments at unprecedented speeds, please visit us at *ripple.com/contact*