Bitcoin Carbon Footprint: Mining Pools Based Estimate Methodology

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Abstract. The paper deals with the cryptoeconomy impact on the environment. The term 'cryptoeconomy' is used for designating the emerging industry around cryptocurrencies and blockchain. Cryptocurrency mining consumes a lot of electricity. As of September 2019, the estimated annual miners' electricity consumption was 78.93 TWh. According to the upper boundary estimation, miners' carbon dioxide emissions were about 80.43 million tons of CO2, which corresponds to 0.24% of the world's total carbon dioxide emissions. The aim of this paper is to develop bitcoin mining carbon footprint estimation methodology. The suggested method is based on the miners' geographical distribution obtained by analyzing the traffic of mining pools login pages. The methodology includes 1) assessment of the miners' geographical distribution; 2) estimation of the miners' carbon dioxide emissions by regions. According to the proposed methodology, miners' carbon dioxide emissions are about 44.12 million tons per year (0.13% of the world's total emissions), which is two times lower than the upper boundary estimate.

Keywords: bitcoin; cryptocurrencies; mining; carbon footprint of bitcoin mining.

1 Introduction

At the current stage of cryptoeconomy development, the following market segments can be identified: exchange and brokerage services, payments, storage and custody (storage of cryptoassets as a service), network consensus services (mining equipment production and operation), infrastructure (design, development, and maintenance of the codebases of cryptoasset networks and related applications), alternative fundraising, banking, and insurance.

This paper focuses on digital mining which provides network consensus services and ensures the integrity of cryptocurrencies' public ledgers, facilitates transactions and prevents double-spending.

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In 2018, the Cambridge Center for Alternative Finance conducted a survey of miners' performance indicators. 22 companies and 35 individual miners from different regions took part in it. According to the survey the indicators were distributed as follows (Table 1).

Table 1. Performance indicators of mining centers (Rauchs et al., 2018).

Indicator	Small Miners[1]	Big Miners
Easy access to electricity	4.37[2]	4.88
Low cost of electricity	4.47	4.88
Friendly regulatory environment	4.37	4.75
Stable political situation	4.37	4.63
High-quality internet connection	4.32	4.38
Cold climate	3.11	4.25
Special incentives for mining activities	3.95	4.13
Availability of skilled labor	3.32	3.75
Cheap land	3.58	3.75
Low crime rate	3.63	3.38

Table 1 shows that the most important indicators for miners are the availability of electricity and its price. This is due to the fact that mining consumes a lot of electricity.

Assuming that electricity for bitcoin mining is generated at the coal-fired power plants only, and knowing its electricity consumption, one can estimate carbon dioxide emissions by the upper bound[3]:

$$m_{CO2} = \phi * E_{estimated},$$

m_{CO2} – carbon dioxide emissions, *kg*

ϕ – air pollution by power generation, *kg / kWh*

$E_{estimated}$ – annual electricity consumption, *kWh*

Cambridge Bitcoin Energy Consumption Index (Rauchs et al., 2019) estimates miners' energy consumption as 78.93 TWh per year. Air pollution for coal-fired power plants vary by type of coal and equipment; according to the World Energy Outlook (IEA, 2017), the world average is 1.019 kg CO_2 / kWh. Thus, the total carbon dioxide emissions are about 80.43 million tons of CO_2, which corresponds to 0.24% of the world's total emissions.

At the same time, electricity produced by a coal-fired power plant has a significantly different environmental footprint comparing to electricity generated by a solar park, for example. Recent studies have shown that the share of renewable energy used by miners is increasing in the overall structure of energy consumption. However, estimates vary significantly – from 20% (Rauchs et al., 2018) to over 70% of the total (Coinshares, 2019).

[1] Small Miners are those who have less than 40 employees

[2] '1' is not important, '2' is not very important, '3' is neutral, '4' is somewhat important, '5' is very important

[3] This model was used to create the Cambridge Bitcoin Electricity Index web service.

Therefore, a clarification of the methodology of estimation of carbon dioxide emissions caused by bitcoin mining is essential.

2 Review of assessment approaches

The assessment of the carbon footprint caused by bitcoin mining has been done in (Foteinis, 2018), (Krause et al, 2018), (McCook, 2018), (Mora et al, 2018), (Stoll et al, 2019), (Vires, 2019). Taking into account the miners' geographical distribution, Stoll (Stoll et al, 2019) suggested using: 1) search results for mining equipment provided by shodan.io; 2) IPs statistics provided by the blockcypher.com; 3) regional statistics provided by slushpool and btc.com.

However, since shodan.io provides information about one thousand devices only, this source cannot be considered as a reliable. The analysis of blockcypher data showed that more than 70% of IPs come from Amazon, which characterizes the blockcypher's servers rather than the actual miners' distribution. Therefore, only slushpool and btc.com were used for the methodology development. But these services provide aggregate statistics, therefore there is a need for further improvements.

The aim of this paper is the development of a methodology of estimation of carbon dioxide emissions caused by bitcoin mining, which takes into account the miners' regional distribution. The methodology includes 1) assessment of the miners' geographical distribution; 2) estimation of the miners' carbon dioxide emissions by regions.

3 Assessment of the miners' geographical distribution using the traffic of mining pools web pages

The proposed approach is based on the traffic analysis of the mining pools login pages. It was assumed that: 1) miners from different regions use login pages in different regions around the world in the same way; 2) traffic measurement systems determine the real location of those who are using VPNs, proxies, and other tools that allow hiding and faking locations.

In order to get miners' regional distribution, consensus-estimate of 3 different internet traffic measurement services were used: SimilarWeb[4], Alexa[5], SemRush[6]. The following login pages have been taken into consideration (Table 2).

[4] https://www.similarweb.com
[5] https://www.alexa.com/siteinfo
[6] https://www.semrush.com

Table 2. Login pages taken into consideration 7.

Notion	Webpage	Hash rate share
[btc]	pool.btc.com	19.43%
[ant]	antpool.com	12.47%
[f2p]	f2pool.com	11.81%
[poo]	poolin.com	9.82%
[slu]	slushpool.com	9.36%
[top]	btc.top	7.77%
[via]	pool.viabtc.com	7.61%
[clu]	bitclubpool.com	1.74%
	Total	**80.01%**

The pools, considered in detail, cover 80% of the global hash rate. Table 3 shows an example of slushpool.com data.

Table 3. Slushpool traffic analysis.

Region	According to Similarweb	According to Semrush	Consensus
C&S America	7.91%	8.76%	10.45%
China		0.37%	0.20%
EU	17.56%	14.92%	20.74%
Eurasia		8.92%	4.83%
Europe	3.54%	8.72%	7.27%
North America	4.48%	3.17%	4.95%
Middle East	4.67%	2.23%	4.58%
Russia	11.65%	11.52%	14.64%
Southeast Asia		0.36%	0.19%
U.S.	19.51%	31.70%	31.23%
other OECD		1.07%	0.58%
South Africa		0.66%	0.36%

Stoll (Stoll et al, 2019) provides aggregate statistics from the slushpool for four macro-regions: CN (China), EU (Europe), US / CA (US and Canada), JP / SG (Japan and Singapore). Taking into account these statistics, we cross-check and adjust the data by regions (Table 4).

[7] https://btc.com/stats/pool

Table 4. Cross-examination of the results of miners' geographical distribution.

Region	Part by traffic	Scoring part
C&S America	10.45%	12.73%
China	0.20%	0.10%
EU	20.74%	16.65%
Eurasia	4.83%	3.12%
Europe	7.27%	5.84%
North America	4.95%	6.03%
Middle East	4.58%	3.67%
Russia	14.64%	11.75%
Southeast Asia	0.19%	0.45%
USA	31.23%	38.04%
OECD	0.58%	1.33%
South Africa	0.36%	0.29%

Given the adjusted data for btc.com and slushpool, the resulting statistics are as follows (Table 5).

Table 5. Geographical distribution statistics.

Region/Pool, %	btc	ant	f2p	poo	slu	top	via	clu	Total
Africa	0.0	0.0	0.0	0.0	0.0	8.0	0.0	0.0	**0.8**
Brazil	2.2	0.0	0.0	0.0	0.0	1.1	3.2	0.0	**0.9**
C&S America	3.8	7.8	1.3	0.0	12.7	2.8	2.2	0.0	**4.3**
China	14.9	17.7	31.8	22.2	0.1	35.6	7.9	0.0	**18.0**
EU	5.6	11.8	5.7	2.5	16.7	19.1	13.4	51.6	**10.5**
Eurasia (other)	0.0	3.2	1.6	0.0	3.1	5.2	0.0	0.0	**1.6**
Europe (other)	7.9	8.9	6.6	6.0	5.8	0.0	9.2	4.2	**6.7**
India	0.0	0.0	0.0	0.0	0.0	2.4	0.0	0.0	**0.2**
Japan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.2	**0.1**
Middle East	23.1	6.3	2.1	22.1	3.7	2.1	7.1	0.0	**10.9**
North America	0.0	0.0	0.0	0.0	6.0	0.9	0.0	0.0	**0.8**
OECD (others)	0.0	0.0	1.4	0.0	1.3	0.0	0.0	2.8	**0.4**
Russia	40.7	27.3	28.9	18.1	11.8	15.2	29.5	6.7	**26.4**
South Africa	0.0	0.0	0.0	0.0	0.3	0.0	0.0	10.3	**0.3**
Southeast Asia	0.0	1.5	4.0	20.4	0.4	1.9	7.0	17.7	**4.6**
USA	1.9	15.5	16.5	8.7	38.0	5.8	20.6	1.5	**13.4**

4 Estimation of the miners' carbon dioxide emissions by regions

The obtained statistics on the miner's geographical distribution (Table 5) were used to estimate carbon dioxide emissions of bitcoin mining (Table 6). The values in the "kgCO2/kWh" column of Table 6 express the average emission factor for generating 1 kWh of electricity in the given region which was obtained from the "IEA World Energy Outlook 2017 Annex A Tables for Scenario Projections". The values of the column "kWh per year" in Table 6 are calculated as follows: the overall electricity consumption estimate (78.93 TWh per year) is multiplied by the share of the region. The share of the region is given in Table 5 (in the column "Total").

Table 6. Carbon dioxide emissions of bitcoin mining.

Region	$kgCO_2/kWh$	kWh per year	$kgCO_2$ per year
Africa	0.625	616648925	385405578
Brazil	0.157	749448315	117663385
C&S America	0.245	3377047232	827376572
China	0.55[8]	14209298675	7815114271
EU	0.351	8318688257	2919859578
Eurasia (other)	0.727	1255237418	912557603
Europe (other)	0.361	5268628795	1901974995
India	0.770	187123877	144085385
Japan	0.536	88999557	47703763
Middle East	0.670	8620282467	5775589253
North America	0.420	625946053	262897342
OECD (others)	0.417	336254977	140218325
Russia	0.750	20860389905	15645292429
South Africa	0.990	204038381	201997997
Southeast Asia	0.600	3643652487	2186191492
USA	0.458	10568333847	4840296902
		78.93 TWh per year	**44.12 million tons of CO_2**

According to the proposed methodology, carbon dioxide emissions are about 44.12 million tons per year (0.13% of global emissions), which is two times lower than the upper boundary estimate.

However, the proposed approach overestimates the proportion of regions with a greater concentration of small miners and underestimates the proportion of regions where large miners are predominant. Having data directly from mining pools would solve this issue. Currently, work in this area is ongoing.

[8] The value for China has been downgraded due to the large share of hydropower used for mining in Sichuan (Stoll et al, 2019)

5 Conclusions and discussion

The paper presents bitcoin mining carbon footprint estimation methodology based on the miners' geographical distribution. The methodology includes 1) assessment of the miners' geographical distribution by analyzing the traffic of mining pools login pages; 2) estimation of the miners' carbon dioxide emissions by regions.

According to the proposed methodology, miners' carbon dioxide emissions are about 44.12 million tons per year which make 0.13% of the world's total emissions. The obtained estimates of electricity consumption and carbon dioxide emissions are approximately twice as high as the results of the Stoll's assessment, partly it could be explained by the significant increase in the bitcoin network hash rate since the publication of his study.

At the same time, miners search for cheap electricity worldwide (e.g. hydropower that occurs in some regions during floods). This leads to reducing carbon dioxide emissions. On the other hand, countries, which produce fossil-fuel electricity (such as Kazakhstan and Iran) are gaining popularity among the miners.

Anyway, increasing electricity consumption may challenge the UN Sustainable Development Goals. The issue of miners' electricity consumption and the corresponding environmental impact should be discussed with policymakers, industry participants and the general public.

References

1. Coinshares (2019). The Bitcoin Mining Network. Retrieved from https://coinshares.co.uk/wp-content/uploads/2019/06/MiningWhitepaperJun2019FinalForeword.pdf
2. Foteinis, S. (2018). Bitcoin's Alarming Carbon Footprint. Nature. Vol. 554 (7691), 169. Retrieved from https://www.nature.com/articles/d41586-018-01625-x
3. International Energy Agency (2017). World Energy Outlook. Retrieved from https://www.iea.org/reports/world-energy-outlook-2017
4. Krause, M. J., Tolaymat, T. (2018). Quantification of Energy and Carbon Costs for Mining Cryptocurrencies. Nature Sustainability. Vol. 1. P. 711–718. Retrieved from https://www.nature.com/articles/s41893-018-0152-7.pdf
5. McCook, H. (2018). The Cost & Sustainability of Bitcoin. Retrieved from https://www.academia.edu/37178295/The_Cost_and_Sustainability_of_Bitcoin_August_2018_
6. Mora, C., Rollin,s R.L., Taladay, K., Kantar, M.B., Chock, M.K., Shimada, M., Franklin, E.C. (2018). Bitcoin Emissions Alone Could Push Global Warming Above 2°C. Nature Climate Change. 2018. Vol. 8. P. 931–933. Retrieved from https://www.nature.com/articles/s41558-018-0321-8.pdf
7. Rauchs, M., Blandin, A., Dek, A. (2019). Cambridge Bitcoin Electricity Consumption Index. Retrieved from https://cbeci.org/

8. Rauchs, M., Blandin, A., Klein, K., Pieters, G., Recanatini, M., Zhang, B. (2018). 2nd Global Cryptoasset Benchmarking Study. Cambridge Centre for Alternative Finance. Retrieved from https://www.jbs.cam.ac.uk/fileadmin/user_upload/research/centres/alternative-finance/downloads/2018-12-ccaf-2nd-global-cryptoasset-benchmarking.pdf
9. Stoll, C., Klaaßen, L., Gallersdörfer, U. (2019). The Carbon Footprint of Bitcoin. Cell. Vol. 3, Issue 7. P. 1647-1661. Retrieved from https://www.cell.com/action/showPdf?pii=S2542-4351%2819%2930255-7
10. Vires, A. (2019). Renewable Energy Will Not Solve Bitcoin's Sustainability Problem. DOI: https://doi.org/10.1016/j.joule.2019.02.007