Commentary:

Energy Consumption of Cryptocurrencies: Looking Beyond Bitcoin

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Summary

Bitcoin's energy hunger has triggered a passionate debate in the academic literature as well as in the general public about the energy consumption of cryptocurrencies. Several scholars have suggested methodologies to estimate Bitcoin's energy consumption, and yet, most studies have been focusing exclusively on Bitcoin and ignored that more than 500 further mineable coins and tokens exist. In this Commentary, we analyze 20 cryptocurrencies with 'proof-of-work' algorithms, which account for more than 98% of the total market capitalization in order to provide a rough estimate of the total energy consumption of cryptocurrencies. Based on the underlying algorithms, current hash-rates, and suitable mining devices, we conclude that Bitcoin accounts for 2/3 of the total energy consumption, while understudied cryptocurrencies represent the remaining 1/3.

Keywords: Bitcoin, Cryptocurrencies, Energy Consumption, Proof-of-work, GHG emissions, ASIC-resistance, Blockchain, Crypto mining

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Introduction

Bitcoin's energy hunger has triggered a passionate debate in the academic literature as well as in the general public about the energy consumption of cryptocurrencies. Bitcoin is a digital currency based on a cryptographically secured distributed ledger and represents the first and best-known blockchain application. Its computationally intensive validation process called 'mining' requires specific hardware and vast amounts of electricity to reach consensus about ownership and transactions. Depending on the methodology and assumptions, energy consumption estimates chart a wide range of results as depicted in Figure 1. The methodologies of the estimates have become more sophisticated over time, and yet, most studies have focused exclusively on Bitcoin and thereby ignored that more than 500 further mineable coins and tokens exist[1].

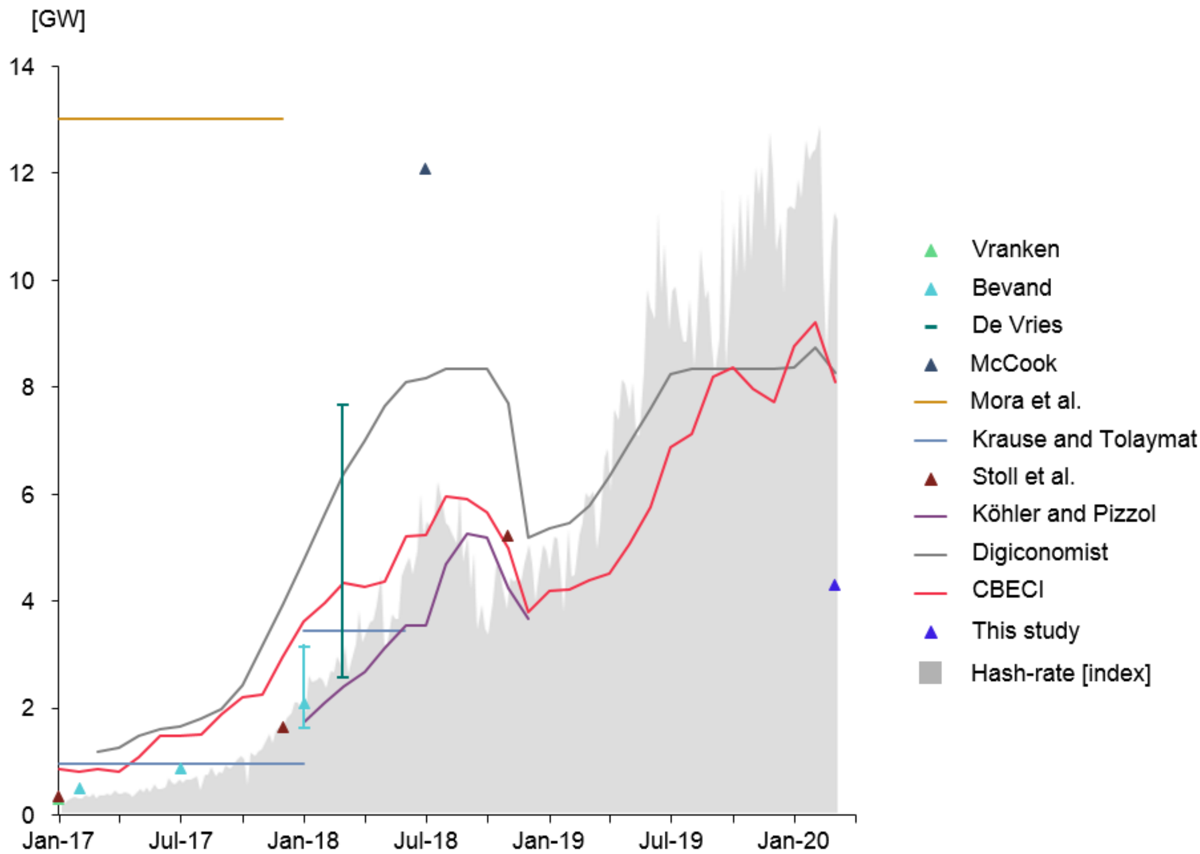

Figure 1 | Bitcoin energy consumption estimates 2017-2020. Energy consumption is presented in gigawatt (GW). Details on the underlying methodologies and date sources can be found in the Supplemental Information Table S1.

Beyond Bitcoin

To estimate the energy consumption of cryptocurrencies beyond Bitcoin, we resort to a methodology proposed by Krause and Tolaymat[2] that employs hash-rates of cryptocurrency networks and suitable mining devices. Hash-rates measure the processing power as they describe the number of attempts per second to solve a block in the so-called 'proof-of-work' mining process. Table 1 lists the hash-rates of the top 20 mineable cryptocurrencies by market capitalization that account for more than 98% of the total market capitalization. These top 20 use 13 different 'proof-of-work' algorithms. Bitcoin, for instance, uses the SHA-256 algorithm that allows for mining with highly specialized, ASIC-based devices, which are considerably more energy-efficient than conventional graphic processing units (GPUs). GPUs are used, for instance, to mine Monero that prevents ASIC-based devices from its validation process[3]. Table 1 lists the efficiency of mining devices that suit the respective algorithms. Dividing the network hash-rates by efficiencies of mining devices yields the rated power of each network. Figure 2 illustrates the cumulative market capitalization and rated power of the top 20 cryptocurrencies: #1 – Bitcoin – accounts for 2/3 of the total energy demand; #2-20 complement 1/3.

#	Name	Symbol	Algorithm	Market cap [USD million]	Market cap [%]	Hashes/s (network)	Efficiency (device) [Hashes/s/W]	Rated power (network) [kW]	Rated power (network) [%]
1	Bitcoin	BTC	SHA-256	122.768	79.69%	1.09E+20	2.53E+10	4.291.366	68.39%
2	Ethereum	ETH	Ethash*	15.209	9.87%	1.64E+14	2.28E+05	719.087	11.46%
3	Bitcoin Cash	BCH	SHA-256	4.183	2.72%	3.88E+18	2.53E+10	153.374	2.44%
4	Bitcoin SV	BSV	SHA-256	3.181	2.07%	3.04E+18	2.53E+10	120.077	1.91%
5	Litecoin	LTC	Scrypt	2.595	1.68%	1.36E+14	8.27E+05	164.796	2.63%
6	Monero	XMR	RandomX*	864	0.56%	1.27E+09	6.00E+00	210.277	3.35%
7	Dash	DASH	X11	639	0.41%	4.59E+15	1.23E+08	37.386	0.60%
8	Ethereum C	ETC	Ethash*	597	0.39%	9.87E+12	2.28E+05	43.278	0.69%
9	Zcash	ZEC	Equihash	310	0.20%	4.42E+09	9.00E+01	49.022	0.78%
10	DogeCoin	DOGE	Scrypt	229	0.15%	1.30E+14	8.27E+05	157.494	2.51%
11	Bitcoin Gold	BTG	ZHash*	133	0.09%	2.64E+06	0.00E+00	8.949	0.14%
12	Decred	DCR	Blake	125	0.08%	4.16E+17	1.89E+10	22.013	0.35%
13	RavenCoin	RVN	X16Rv2*	89	0.06%	3.14E+13	1.16E+05	270.792	4.32%
14	MonaCoin	MONA	Lyra2REv2	85	0.05%	9.16E+13	1.17E+07	7.844	0.13%
15	Bytom	BTM	Tensority	61	0.04%	5.30E+08	1.82E+02	2.915	0.05%
16	SiaCoin	SC	Sia	55	0.04%	5.70E+15	1.22E+09	4.664	0.07%
17	DigiByte	DGB	SHA-256	53	0.03%	6.60E+16	2.53E+10	2.608	0.04%
18	Horizen	ZEN	Equihash	48	0.03%	6.86E+08	9.00E+01	7.606	0.12%
19	Komodo	KMD	Equihash	46	0.03%	6.08E+07	9.00E+01	674	0.01%
20	Bytecoin	BCN	CryptoNight	43	0.03%	2.33E+08	5.00E+02	467	0.01%
TOTAL				**151.315**	98.23%			**6.274.688**	100%

*ASIC-resistant algorithms

Table 1 | Top 20 mineable cryptocurrencies by market capitalization on 03/27/2020. The table displays the top 20 mineable currencies with their respective algorithms, efficiencies of suitable mining devices, and rated power of the networks. Details on methodology, data, and sources can be found in the Supplemental Information Table S2, Table S3, and Table S4.

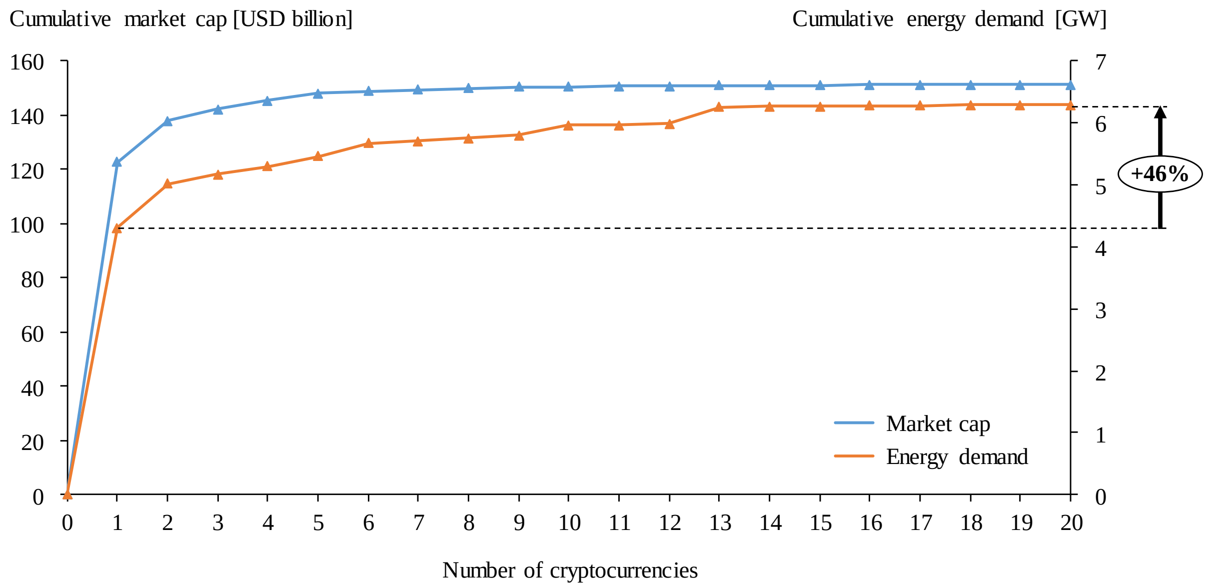

Figure 2 | Cumulative market capitalization and energy demand of top 20 currencies by market capitalization. Data sources: own calculations (see Table 1); values as of 03/27/2020.

It is important to note that currencies with ASIC-resistant algorithms consume an overproportionate amount of energy in relation to their market capitalization. As listed in Table 1, RavenCoin, for instance, accounts for 4.32% of the total rated power, while its market cap only accounts for 0.06% of the considered top 20. A second example is Monero, which became ASIC-resistant after an update in March 2018. The update led to an abrupt decrease in the network's computational power of more than 80%. After a few days, the hash-rate bounced back to half of the pre-update level as miners switched from ASIC to less energy-efficient GPUs.[3]

In absolute terms, the total energy consumption estimate in Figure 1 appears rather conservative. Alternative estimation methods (including e.g., auxiliary losses in mining facilities) suggest that the actual energy consumption of Bitcoin might be higher: Digiconomist[4], for instance, derives 7.9 gigawatts (GW), and the Cambridge Bitcoin Electricity Consumption Index (CBECI)[5] states 6.1 GW, while we estimate 4.3 GW (all estimates with cutoff date 03/27/2020). The CBECI uses a bottom-up approach, while Digiconomist applies a top-down approach (which has been criticized for potential overestimating in the past[6]). As we consistently apply the bottom-up approach of Krause and Tolaymat[2] to all 20 currencies, potentially higher absolute numbers would not impair the relative shares (if we assume the neglected factors apply to all currencies equally).

Nonetheless, all energy estimates and underlying assumptions are subject to uncertainty. In particular, the selections and operation of the mining devices pose a significant challenge as the mining industry operates secretively. Miners may shut down and ramp up certain devices temporarily as a response to variations in electricity prices and market prices (i.e., when electricity costs exceed mining revenues; as seen during coronavirus pandemic when market prices and hash-rates tumbled)[7]. Including outdated and unprofitable mining devices in the estimate has been found to distort the energy demand estimate and overvalue the resulting carbon emissions by a factor of 4.5[8]. Here again, potential changes in absolute numbers would likely impair the estimates of all cryptocurrencies in a similar manner.

Environmental Impacts

Energy consumption, per se, is not an issue in the context of climate change. For instance, clean generation resources, such as wind and solar, produce energy without emitting greenhouse gases (GHG) (which trap heat in the atmosphere and cause cost – now and for future generations). Fossil generation resources – most prominently coal and gas – cause such GHG emissions. Consequently, the emission factor of electricity depends on the constitution of the generation resource mix, which varies among countries as well as regions. The relative energy demand of cryptocurrencies in Table 1 could be used to roughly estimate GHG emissions. To derive a profound estimate of caused GHG emissions, however, more research is needed into currency-specific factors such as the respective footprint of mining operations.

Translating energy consumption into GHG emissions adds further uncertainty. Krause and Tolaymat[2], for instance, use average emission factors of electricity consumption in several countries to chart a range of potential results, which vary by a factor of over 4 between the lowest and highest value. As miners seek locations with low electricity prices, other studies assume high shares of cheap renewable energy, which results in much lower emissions estimates[9]. From a power system perspective, the most accurate approach would be to consider marginal emission factors. Mining operations cause an additional load that activates additional generation resources. The increase in full-load hours of certain generation resources may lead to fuel switching effects and alter local emission intensities[7]. As this approach requires exact mining locations and load information – which are extremely hard to get – Stoll et al.[10] use average emission factors as a proxy to balance the effect of higher emissions at the margin and mining in regions with high shares of clean energy.

Conclusions

We show in this Commentary the necessity to broaden the debate on the environmental impacts of cryptocurrencies – beyond Bitcoin. Irrespective of the uncertainty in assessing the energy demand and associated GHG emissions of cryptocurrencies, our estimate for understudied currencies underlines the importance of including these into the debate. Based on the underlying algorithms, current hash-rates, and suitable mining devices, we conclude that Bitcoin accounts for 2/3 of the total energy consumption, while understudied cryptocurrencies represent the remaining 1/3. Therefore, understudied currencies add nearly 50% on top of Bitcoin's energy hunger, which already alone may cause considerable environmental damage[10]. Including the remaining hundreds of mineable coins and tokens, which account for the 1.77% market capitalization not captured by the top 20, would further increase the share of energy consumption caused by cryptocurrencies besides Bitcoin.

Going forward, a holistic understanding of the environmental impacts may also help policymakers to set the right rules for cryptocurrencies and blockchain applications in general. Most academic studies have been focusing not only exclusively on Bitcoin but also primarily on externalities resulting from the energy consumption during the mining process. Although the use phase predominantly contributes to the carbon footprint of conventional data centers[11], this might not apply to cryptocurrencies given the high price volatility and technological changes. Translating the total energy consumption into carbon emissions, and including embedded emissions of mining device production as well as e-waste[12], would further complement the picture, and reveal the total environmental damage caused by cryptocurrencies.

The insights from cryptocurrencies may also be applied to novel blockchain applications that are rapidly maturing. In the energy sector, for instance, an increasing number of blockchain use cases have emerged, ranging from peer-to-peer energy trading to the management of carbon emissions to mitigate climate change[13; 14]. Based on the lessons learned from cryptocurrencies, however, it is important to carefully differentiate between energy-hungry algorithms and energy-efficient algorithms (e.g. private/permissioned networks do not need energy-intense validation processes), and find the right balance between deep details and big picture.

Supplemental information

Supplemental Information can be found online at [doi].

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Author contribution

All authors contributed equally.

Declaration of Interests

The authors declare no competing interests.

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