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[1]Nuclear Innovation Alliance, Washington, D.C., USA

[2]Payne Institute for Public Policy, Colorado School of Mines, Golden, CO, USA

[3]Energy Policy and Climate Program, Kreiger School of Arts & Sciences, Johns Hopkins University, Washington, D.C., USA

[4]Department of Public Policy, Division of Economics and Business, Colorado School of Mines, Golden, CO, USA

*Correspondence:
agilbert@nuclearinnovationalliance.org

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Commentary

# Energy Consumption of Cryptocurrencies Beyond Bitcoin

Ulrich Gallersdörfer,[1]
Lena Klaaßen,[2]
and Christian Stoll[3,4,*]

Ulrich Gallersdörfer is a research associate in the Department of Informatics at the Technical University of Munich. His research focuses on identity management in blockchains. His interest extends to further aspects of the technology, ranging from environmental implications to data analytics applications.

Lena Klaaßen is a graduate student at TUM School of Management at the Technical University of Munich. She is specialized in energy markets and accounting. Her research focuses on carbon accounting in the corporate and cryptocurrency space. She has previously analyzed blockchain-related firms for a venture capital fund.

Christian Stoll conducts research at the Center for Energy and Environmental Policy Research at the Massachusetts Institute of Technology and at the Center for Energy Markets of the Technical University of Munich. His research focuses on the implications of climate change from an economic point of view.

Bitcoin's energy hunger has triggered a passionate debate in 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]

## 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; 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.

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, whereas 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, whereas we estimate 4.3 GW (all estimates with a cutoff date of 03/27/2020;

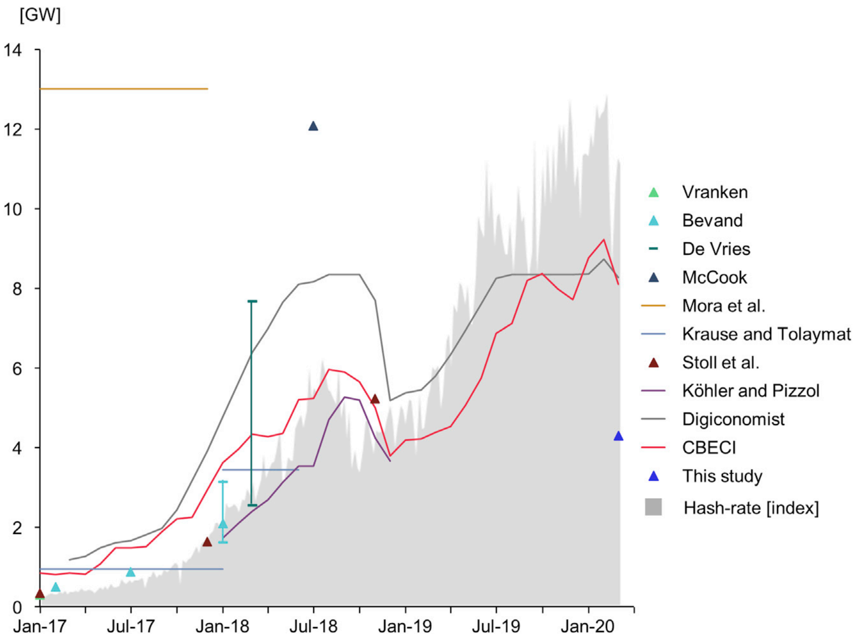


**Figure 1. Bitcoin Energy Consumption Estimates 2017–2020**
Energy consumption is presented in gigawatt (GW). Details on the underlying methodologies and date sources can be found in the Supplemental Information and Table S1.

note: Figure 1 shows monthly averages for Digiconomist and CBECI). The CBECI uses a bottom-up approach, whereas Digiconomist applies a top-down approach (which has been criticized for potential overestimating in the past[6]). Given that 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 given that 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 values. 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 in 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, and 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

**Table 1. Top 20 Mineable Cryptocurrencies by Market Capitalization on 03/27/2020**

| # | 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[a] | 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[a] | 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[a] | 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[a] | 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[a] | 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% |

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 and Tables S2, S3, and S4.
[a]ASIC-resistant algorithms

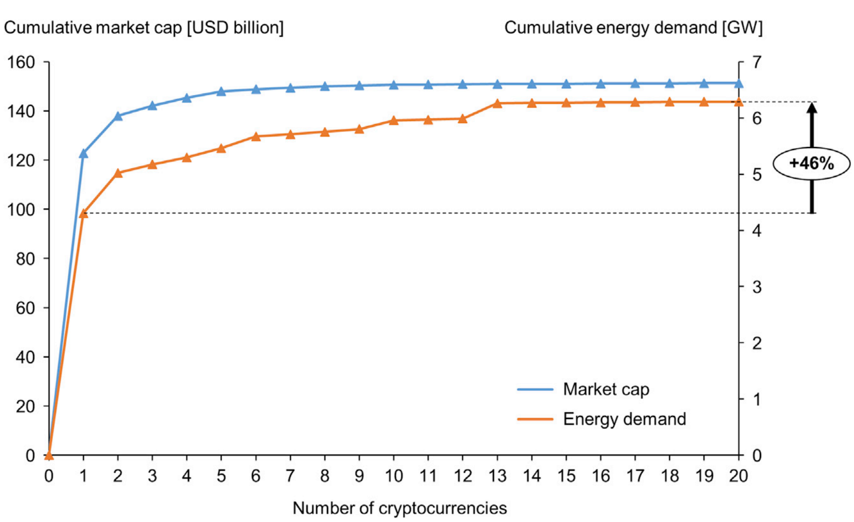


**Figure 2. Cumulative Market Capitalization and Energy Demand of Top 20 Currencies by Market Capitalization**
Data sources: own calculations (see Table 1); values as of 03/27/2020.

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 https://doi.org/10.1016/j.joule.2020.07.013.

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## AUTHOR CONTRIBUTIONS

All authors contributed equally.

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[1]TUM Software Engineering for Business Information Systems, Department of Informatics, Technical University of Munich, Munich, Germany

[2]TUM School of Management, Technical University of Munich, Munich, Germany

[3]MIT Center for Energy and Environmental Policy Research, Massachusetts Institute of Technology, Cambridge, MA, USA

[4]TUM Center for Energy Markets, TUM School of Management, Technical University of Munich, Munich, Germany

*Correspondence: cstoll@mit.edu

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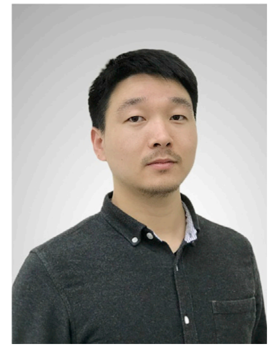
Commentary

# Toward High-Voltage Aqueous Batteries: Super- or Low-Concentrated Electrolyte?

**Dongliang Chao[1,*] and Shi-Zhang Qiao[1,*]**



Dongliang Chao obtained his PhD from Nanyang Technological University (NTU, Singapore). He joined the University of California, Los Angeles (UCLA, USA) in 2016 as a joint researcher. He is currently an ARC DECRA Fellow at the University of Adelaide (UoA, Australia), working on electrochemical mechanism and practical application of materials for next-generation safe, low-cost, and scalable energy storage. He is serving as the managing editor of *Materials Today Energy*. He was recently honored with the prestigious Innovators Under 35 (2020, MIT Technology Review), ARC Discovery Project (2019), and the Emerging Researcher (2019, Royal Society of Chemistry).

Shi-Zhang Qiao is currently a chair professor at School of Chemical Engineering and Advanced Materials of the University of Adelaide. His research expertise is in nanostructured materials for new energy

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## Supplemental Information

# Energy Consumption of Cryptocurrencies Beyond Bitcoin

**Ulrich Gallersdörfer, Lena Klaaßen, and Christian Stoll**

## Contents of this file

Table S1 provides details on the studies depicted in overview of Bitcoin energy consumption estimates, related to Figure 1 in the main body.

Table S2 provides details on data sources of input parameters (market capitalization, algorithms, and has-rates), related to Table 1 in the main body.

Table S3 provides details on reference hardware for ASIC-compatible algorithms, related to Table 1 in the main body.

Table S4 provides details on reference hardware for ASIC-resistant algorithms (GPUs), related to Table 1 in the main body.

Remarks on data validity.

## Supplemental Data Items

**Table S1. Details on the studies depicted in overview of Bitcoin energy consumption estimates, related to Figure 1 in the main body.**

Figure 1 in the Commentary's main body depicts the electricity consumption estimates of the Bitcoin network. Table S1 provides details on the studies depicted in Figure 1 (from 01/2017 until 03/2020). Most study results reflect the electricity consumption of the Bitcoin network at a specific date. Some studies state an average consumption or ranges over a period of time, as highlighted in the third column of Table S1. The indexed hash-rate (the computing power of the network) charted in Figure 1 is retrieved from Blockchain.com[1].

| Study | Date | Observation | Estimate [MW] |
|---|---|---|---|
| Vranken[2] | 01/01/2017 | Cutoff date | 100-500[a] |
| Bevand[3] | 02/26/2017 | Cutoff date | 470-540[b] |
| | 07/28/2017 | | 816-944[b] |
| | 01/11/2018 | | 2,100[b] |
| De Vries[4] | 03/2018 | Cutoff date | 2,550-7,670[c] |
| McCook[5] | 06/19/2018 | Cutoff date | 12,080[d] |
| Mora et al.[6] | 2017 | Period average | 13,010[e] |
| Krause and Tolaymat[7] | 2017 | Period average | 948[f] |
| | 2018 (first half-year) | | 3,441[f] |
| Stoll et al.[8] | 12/2016 | Cutoff date | 345[g] |
| | 12/2017 | | 1,637[g] |
| | 11/2018 | | 5,232[g] |
| Köhler and Pizzol[9] | 2018 | Period average | 3,571[h] |
| Digiconomist[10] | 03/2017-03/2020 | Period range | 1,182-8,272[i] |
| CBECI[11] | 01/2017-03/2020 | Period range | 847-8,095[j] |
| This study | 03/27/2020 | Cutoff date | 4,291 |

**Table S1 | Details on the studies depicted in overview of Bitcoin energy consumption estimates.** Estimates are presented in megawatt (MW). a. range derived from lower limit (miners use state-of-the-art hardware) and upper limit (miners spend revenues on energy), b. ranges calculated by a bottom-up approach assuming different hardware mixes, c. lower limit assumes miners use state-of-the-art hardware; upper limit assumes miners spend 40% of all revenues on hardware and 60% on electricity and represents a scenario possibly applicable in the future, d. only figure that includes the power spent on manufacturing of the mining hardware, which represents 57% of this total power estimate; power usage effectiveness (PUE) of 1.25 considered, e. calculation based on the flawed assumption that the number of transactions drives power consumption, f. bottom-up approach deploying hash-rates and miners device efficiencies, g. bottom-up approach; PUE of 1.05 considered, h. 27.14 milliwatt hours/terahash; translated in monthly averages with total annual as of 2018, i. historical development of monthly averages; estimates calculated by assuming 60% of revenues are spent on operational costs incl. electricity, hardware, and cooling costs, j. Historical development of monthly averages using a bottom-up approach; PUE of 1.1 considered.

**Table S2. Data sources of input parameters, related to Table 1 in the main body.**

Table 1 in the main body of the Commentary displays the top 20 mineable currencies with their respective algorithms, hash-rates of the networks, the efficiency of suitable hardware, and rated power of the networks. Table S2 lists the data sources of underlying input parameters.

| Input parameter | Data source |
|---|---|
| Market capitalization | CoinMarketCap[12] |
| Hash algorithms | WhatToMine[13] |
| Network hash-rate: BTC, ETH, BCH, BSV, LTC, XMR, DASH, ETC, ZEC, DOGE, BTG | CoinMetrics.io[14] |
| Network hash-rate: RVN, MONA, DGB, ZEN | CoinWarz[15] |
| Network hash-rate. KMD, BCN | WhatToMine[13] |
| Network hash-rate: DCR | dcrstats.com[16] |
| Network hash-rate: BTM | tokenview.com[17] |
| Network hash-rate: SC | siastats.info[18] |

**Table S2 | Data sources of input parameters of Table 1.**

**Table S3. Reference hardware for ASIC-compatible algorithms, related to Table 1 in the main body.**

For each currency we decide – depending on the ASIC-resistance of the PoW-algorithm – which hardware to select. If the algorithm is ASIC-compatible, we rely on hardware estimates of WhatToMine[13]. Table S3 depicts ASIC-hardware used in our calculation. We verified the data for speed and energy consumption with ASICMinerValue[19]. We validated the collected data with information on manufacturers' websites if a device was not available on both ASICMinerValue and WhatToMine.

| Algorithm | Hardware | Speed [Hashes/s] | Rated Power [W] | Efficiency [Hashes/s/W] |
|---|---|---|---|---|
| SHA-256 | Bitmain Antminer S17 Pro 53TH | 5.3E+13 | 2,094 | 2.53E+10 |
| Scrypt | Innosilicon A4+ LTCMaster | 6.2E+08 | 750 | 8.27E+05 |
| X11 | Spondoolies SPx36 | 5.4E+11 | 4,400 | 1.22E+08 |
| Blake | Bitmain Antminer DR5 | 3.4E+13 | 1,800 | 1.89E+10 |
| Equihash | Innosilicon A9++ ZMaster | 1,4E+05 | 1,550 | 9.00E+01 |
| CryptoNight | Innosilicon A8+ CryptoMaster | 2.4E+05 | 480 | 5.00E+02 |
| Tensority | Bitmain Antminer B7 | 9.8E+04 | 528 | 1.82E+02 |
| Lyra2REv2 | FusionSilicon X1 Miner | 1.296E+10 | 1,110 | 1.17E+07 |
| Sia | Obelisk SC1 Slim | 5.5E+11 | 450 | 1.22E+09 |

**Table S3 | Reference hardware for ASIC-compatible algorithms.**

**Table S4. Reference hardware for ASIC-resistant algorithms (GPUs), related to Table 1 in the main body.**

| | | | Ethash | | RandomX | | ZHash | | X16Rv2 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Device name | | Release date | Speed [Mh/s] | Rated power [W] | Speed [h/s] | Rated power [W] | Speed [h/s] | Rated power [W] | Speed [Mh/s] | Rated power [W] |
| AMD | Radeon R9 380 | June 2015 | 19 | 140 | *n.a.* | *n.a.* | 16 | 120 | 3.9 | 130 |
| | Radeon R9 Fury | June 2015 | 29 | 220 | *n.a.* | *n.a.* | 32 | 240 | 13 | 270 |
| | Radeon RX 470 | June 2016 | 26 | 120 | 340 | 80 | 18 | 110 | 9.5 | 130 |
| | Radeon RX 480 | June 2016 | 29.5 | 135 | 470 | 90 | 21 | 120 | 11.5 | 140 |
| | Radeon RX 570 | April 2017 | 27.9 | 120 | 390 | 80 | 19 | 100 | 10 | 120 |
| | Radeon RX 580 | April 2017 | 30.2 | 125 | 470 | 90 | 21 | 110 | 11.5 | 130 |
| | Radeon RX Vega 56 | August 2017 | 36.5 | 180 | 1040 | 150 | 34 | 230 | 16 | 230 |
| | Radeon RX Vega 64 | August 2017 | 40 | 200 | 1160 | 160 | 38 | 250 | 18 | 250 |
| | Radeon RX 5700XT | July 2019 | 51.5 | 140 | *n.a.* | *n.a.* | *n.a.* | *n.a.* | *n.a.* | *n.a.* |
| | Radeon VII | February 2019 | 78 | 230 | 1400 | 170 | 49 | 180 | 23 | 240 |
| Nvidia | GTX 1050 Ti | October 2016 | 13 | 80 | 200 | 60 | 19 | 80 | 8 | 80 |
| | GTX 1060 | August 2016 | 22.5 | 90 | 350 | 80 | 32.5 | 90 | 9.4 | 90 |
| | GTX 1070 | June 2016 | 30 | 130 | 560 | 120 | 56 | 130 | 18 | 130 |
| | GTX 1070 Ti | October 2017 | 30.5 | 130 | 640 | 120 | 59 | 130 | 19.5 | 130 |
| | GTX 1080 | May 2016 | 34.5 | 170 | 700 | 120 | 67 | 160 | 23 | 150 |
| | GTX 1080 Ti | September 2017 | 45.5 | 180 | 1030 | 160 | 86 | 200 | 31 | 190 |
| | GTX 1660 | March 2019 | 20.5 | 90 | 530 | 90 | 37 | 90 | 17 | 90 |
| | GTX 1660 Ti | February 2019 | 25.7 | 90 | 580 | 90 | 39 | 90 | 17.2 | 90 |
| | RTX 2060 | January 2019 | 27.6 | 130 | 600 | 110 | 57 | 130 | 22 | 130 |
| | RTX 2070 | October 2018 | 36.9 | 150 | 700 | 140 | 62 | 150 | 24.5 | 150 |
| | RTX 2080 | September 2018 | 36.9 | 190 | 1000 | 150 | 88 | 190 | 33.5 | 190 |
| | RTX 2080 Ti | September 2018 | 52.5 | 220 | 1380 | 190 | 100 | 220 | 41 | 220 |
| | **Overall Efficiency [Hashes/s/W]** | | **228,128.83** | | **6.02** | | **0.30** | | **116,006.10** | |

**Table S4 | Reference hardware for ASIC-resistant algorithms.** For algorithms that are ASIC-resistant, Table S4 depicts the hardware selection, release date, hash-rates, and energy consumption for four ASIC-resistant algorithms. In the bottom line, the overall efficiency of all cards is displayed for the respective algorithm. We rely equally on all 22 GPUs suggested by WhatToMine. Some values are not available on WhatToMine. We marked them as *n.a.* (not available) and exclude them in our estimates.

## Remarks on data validity

- **Device selection**: We select ASIC hardware and graphics cards according to data provided by WhatToMine. For ASIC-compatible algorithms, we assume one representative device per algorithm (see Table S3). For ASIC-resistant algorithms, we take a multitude of suitable devices into account. Deciding on the distribution of hardware devices is highly challenging, primarily due to the vast number of GPUs available. We build our estimate on popular GPUs suited for mining as suggested by WhatToMine. It is noteworthy that considerable differences in efficiencies exist among the selected GPUs and that the release dates not necessarily correlate with efficiencies (for Ethash algorithm e.g., Nvidia GTX 1060 with release date 08/16 is 28% more efficient than Nvidia RTX 2080, which was released more than two years later in 09/18). To account for the diversity in the graphics card ecosystem, we assume an equal distribution across the listed graphics cards. This assumption we have to make on the GPU distribution due to limited empirical evidence adds a certain degree of uncertainty. Assuming a different distribution would change the absolute results according to the efficiencies of overweighed GPUs.

- **Optimized devices**: WhatToMine provides hash-rates and energy usage of GPUs with settings that enhance the efficiency of the device. This is facilitated by increasing or decreasing GPU clock speed, lowering voltage, or installing a custom basic input/output system (BIOS). Generally, this affects our estimates as not all miners might apply these settings, and as not all GPUs are affected by such optimization equally (e.g., due to chip quality). Future research may validate these estimates and provide more accuracy here by physically measuring the energy efficiency of different GPUs in certain configurations.

- **Further inefficiencies**: Our estimate does not include power usage effectiveness (e.g., losses due to cooling, or cable and transformer losses), or other auxiliary energy costs (e.g., GPUs require additional hardware such as a mainboard or CPU). Additionally, the rated power is not equal to measured (and consumed) power of devices. Such aspects add further uncertainty to the absolute energy consumption figures per single cryptocurrency, as we directionally underestimate the energy consumption compared to other approaches (as seen in Table S1, and as suggested by the comparison of our results with more sophisticated methodologies for Bitcoin (see main body for details)). However, as this inaccuracy applies to all examined cryptocurrencies, potential changes in absolute numbers would likely impair the estimates of all cryptocurrencies in a similar manner, and not impair the relative shares. Future research into understudied coins (besides Bitcoin) may provide more certainty on absolute figures.

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