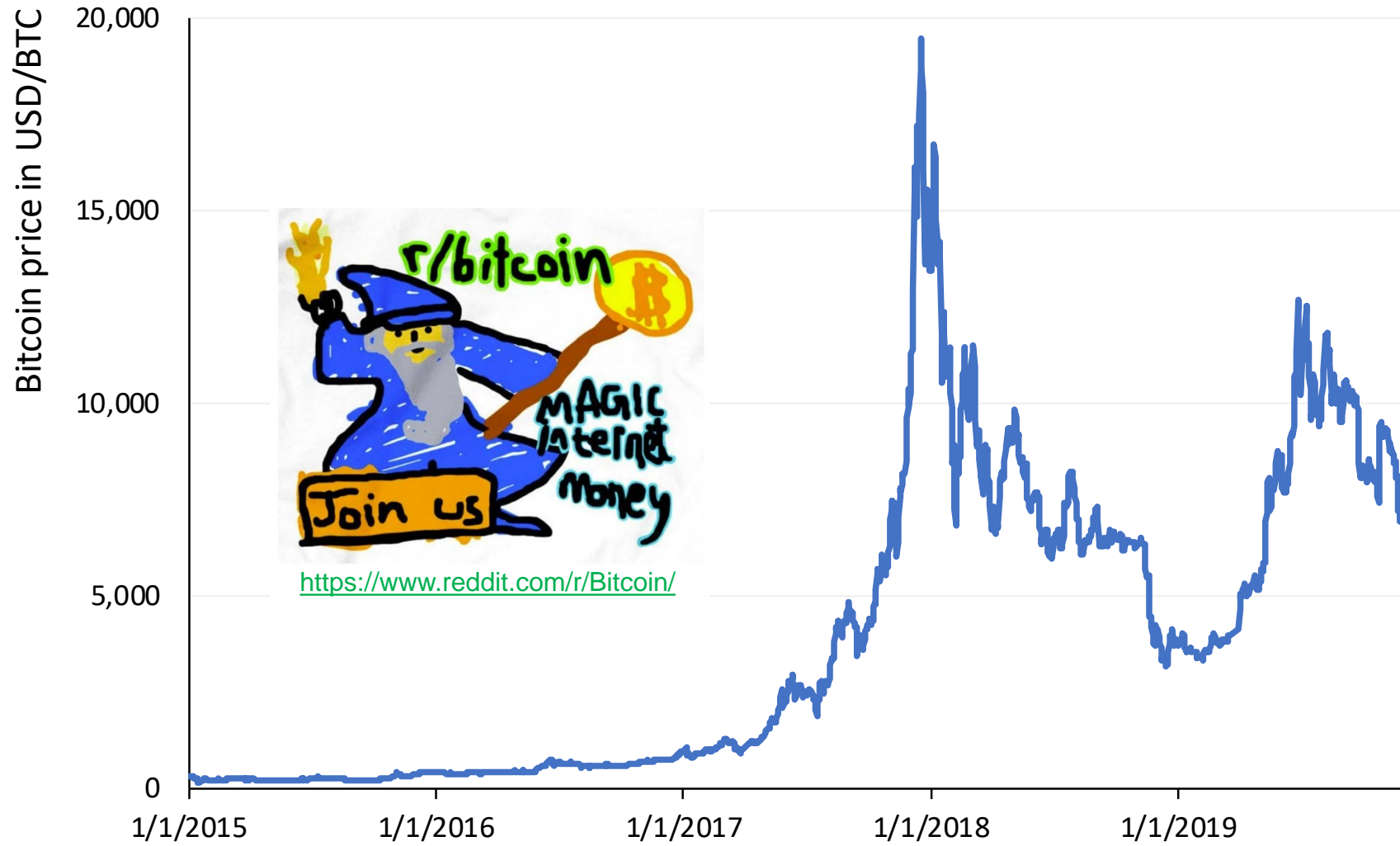# How dangerous are Bitcoin emissions for global climate?
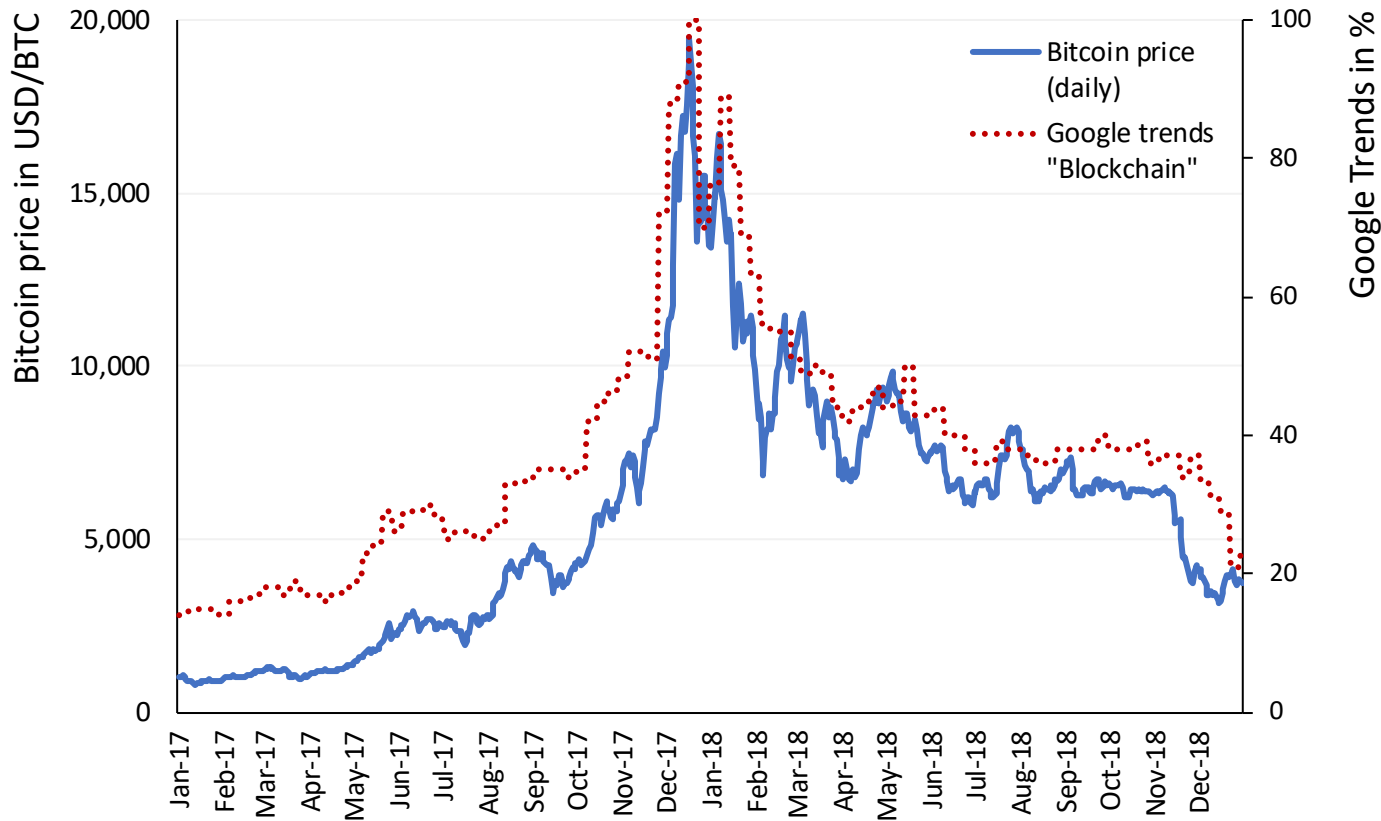
ESI Seminar, Energy Studies Institute
National University of Singapore

Singapore, 4 December 2019

FCN | Future Energy Consumer Needs and Behavior

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Bitcoin: Via darknet into global hype and significant industry

https://www.reddit.com/r/Bitcoin/

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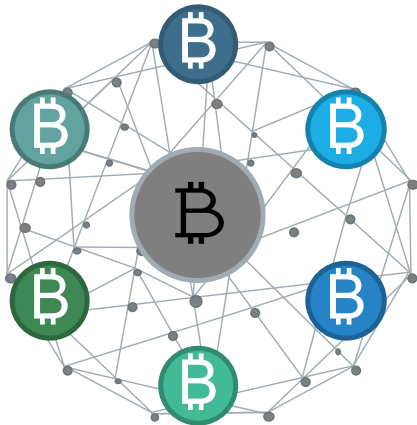
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Bitcoin: "Mother of all blockchains"

- ➢ Blockchain technology originated from Bitcoin
- ➢ Interest in blockchain technology correlates with Bitcoin price

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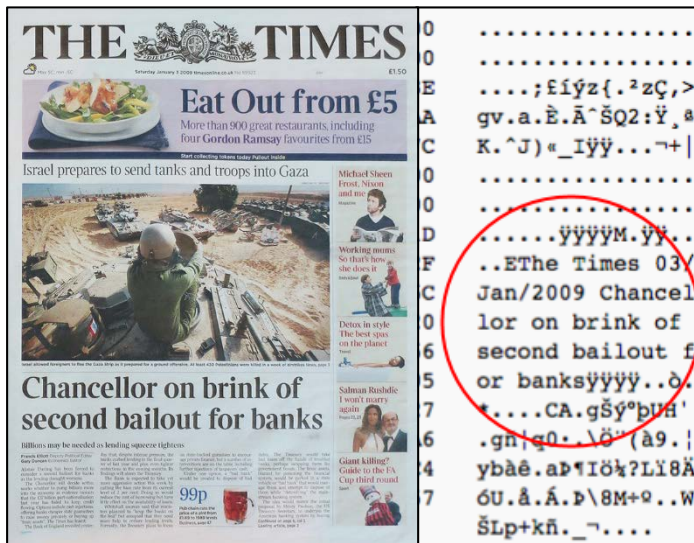
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What is Bitcoin?

- Origin: Whitepaper from Satoshi Nakamoto (2008): "Bitcoin: A Peer-to-Peer Electronic Cash System"

- A peer-to-peer payment network without any central authority of "trust" (e.g. central bank, credit card company) for the prevention of fraud (double spending)

- Transactions are grouped into blocks and recorded network-wide in distributed ledgers

- Blocks are cryptographically linked up to the first ("genesis") block by the mining procedure

- This procedure creates an irreversible "chain of blocks": the blockchain

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Purpose of peer-to-peer cryptocurrency Bitcoin

Source: Medium (2019)

➢ Bitcoin's genesis block contains a reference to a headline article from "The Times" from 3 Jan 2009

➢ Proof that genesis block was created on or after 3 Jan 2009 – shortly after the global financial crisis

➢ Nakamoto probably also intended to criticize current system of fractional-reserve banking

➢ Also a criticism that authorities in (liberal) systems are rescuing private banks with public money

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What is Bitcoin mining?

➢ Bitcoin mining is a "consensus mechanism" (so-called "Proof-of work") to ensure trust in the cryptocurrency

➢ PoW is a computing-intensive puzzle (hashing) and miners compete in a "rent-seeking contest"

➢ Miners are incentivized to participate through rewards and transaction fees in the form of issued bitcoins

➢ All successful Bitcoin transactions in the blockchain have been verified and are digitally signed by miners
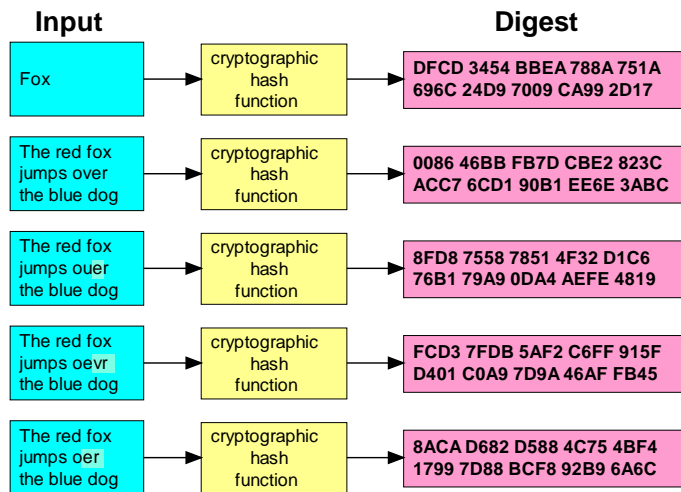
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Rewards and transaction fees as incentive in Bitcoin mining

- The fastest successful miner (winner of the rent-seeking contest) is awarded with bitcoins

- Awarded bitcoins consist of rewards (new bitcoins) and transaction fees (existing bitcoins paid by sender)

- Bitcoin rewards for successfully mining a block halve every four years (210,000 blocks à 10 minutes)

- Initially, 50 bitcoins as reward per block – today, 12.5 bitcoins

- With this, there is an upper limit on maximum number of bitcoins (21 million) which will be reached in 2140
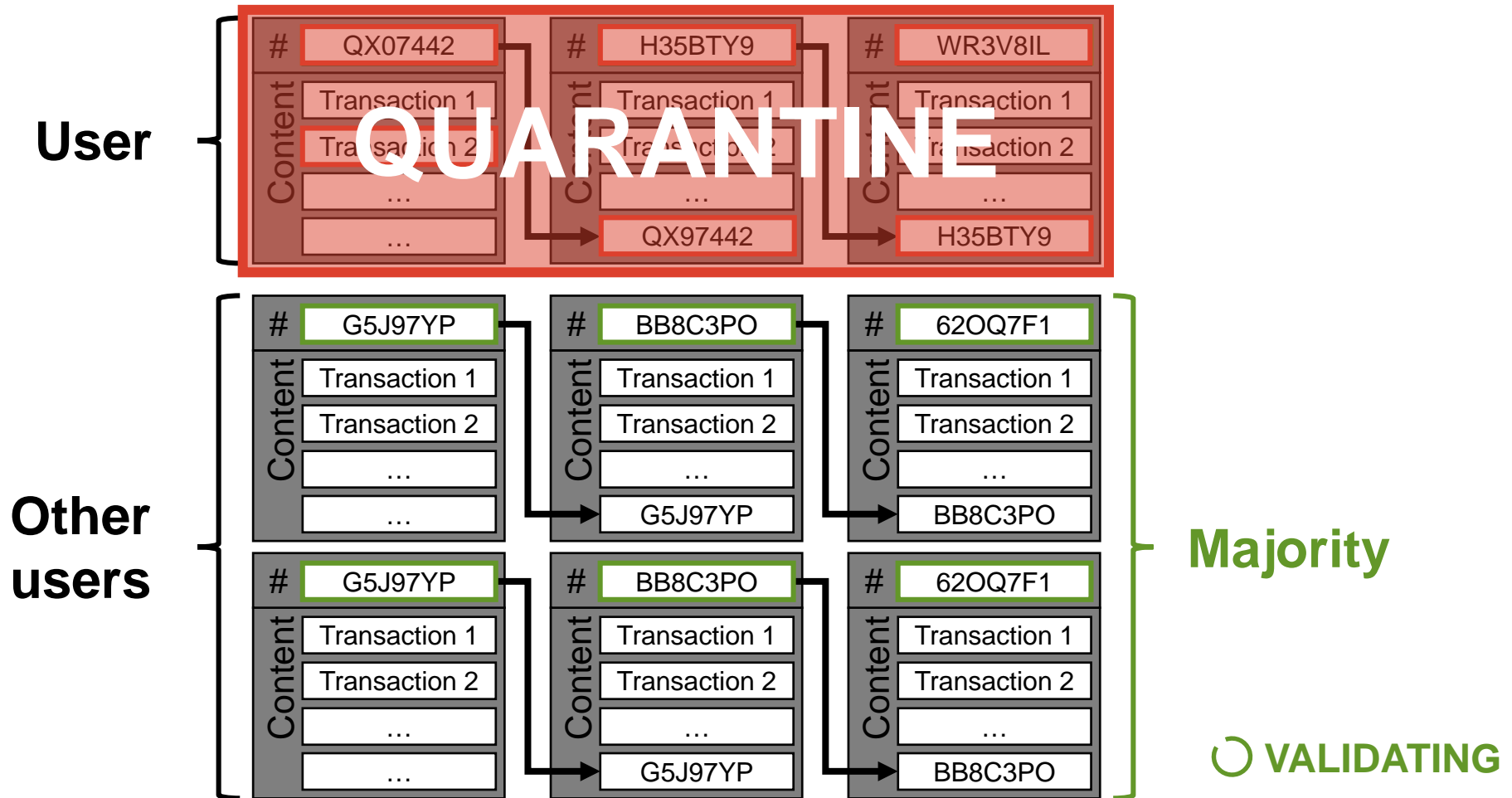
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How does hashing work?

Input		Digest
Fox	cryptographic hash function	DFCD 3454 BBEA 788A 751A 696C 24D9 7009 CA99 2D17
The red fox jumps over the blue dog	cryptographic hash function	0086 46BB FB7D CBE2 823C ACC7 6CD1 90B1 EE6E 3ABC
The red fox jumps ouer the blue dog	cryptographic hash function	8FD8 7558 7851 4F32 D1C6 76B1 79A9 0DA4 AEFE 4819
The red fox jumps oevr the blue dog	cryptographic hash function	FCD3 7FDB 5AF2 C6FF 915F D401 C0A9 7D9A 46AF FB45
The red fox jumps oer the blue dog	cryptographic hash function	8ACA D682 D588 4C75 4BF4 1799 7D88 BCF8 92B9 6A6C

➢ Hash function is a mathematical one-way algorithm which is infeasible to invert

➢ Input data can be of arbitrary length but output data (hash value) is of fixed length and unambiguous

➢ Only way to identify input data from hash value is trial-and-error ("brute force method")

➢ Guessing the correct input data requires an enormous number of trials on average (energy intensive)

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Achieving security in a decentralized peer-to-peer blockchain

- ➤ The more miner a decentralized blockchain has, the higher its security
- ➤ The higher a (crypto-)currency's security, the higher the users' trust in it

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The study: Bitcoin emissions alone could threaten global climate

Forbes

Bitcoin Predicted To Be The Nail In The Coffin Of Climate Change

Comment | Published: 29 October 2018

Bitcoin emissions alone could push global warming above 2°C

Camilo Mora ✉, Randi L. Rollins, Katie Taladay, Michael B. Kantar, Mason K. Chock, Mio Shimada & Erik C. Franklin
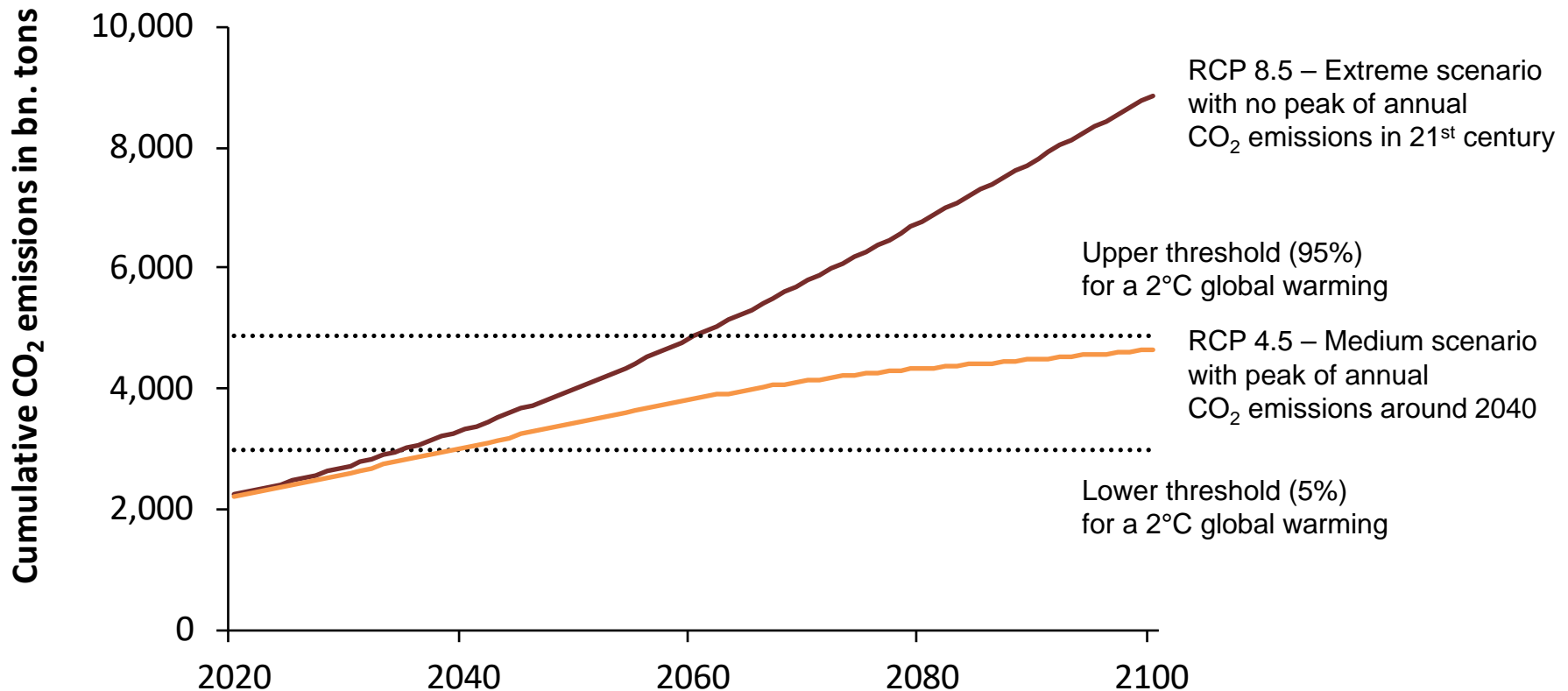
Source: Dittmar (2019)

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IPCC projections on cumulative global greenhouse gas emissions

Chart showing cumulative CO_2 emissions in bn. tons (y-axis, 0 to 10,000) versus years (x-axis, 2020 to 2100).

- RCP 8.5 – Extreme scenario with no peak of annual CO_2 emissions in 21st century
- Upper threshold (95%) for a 2°C global warming
- RCP 4.5 – Medium scenario with peak of annual CO_2 emissions around 2040
- Lower threshold (5%) for a 2°C global warming

➤ Mora et al. (2018): "Reducing emissions to keep warming below 2 °C is already regarded as a very difficult challenge given the increasing human population and consumption as well as a lack of political will."

➤ Mora et al. (2018): "Then came Bitcoin."

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Key results of Mora et al. (2018)
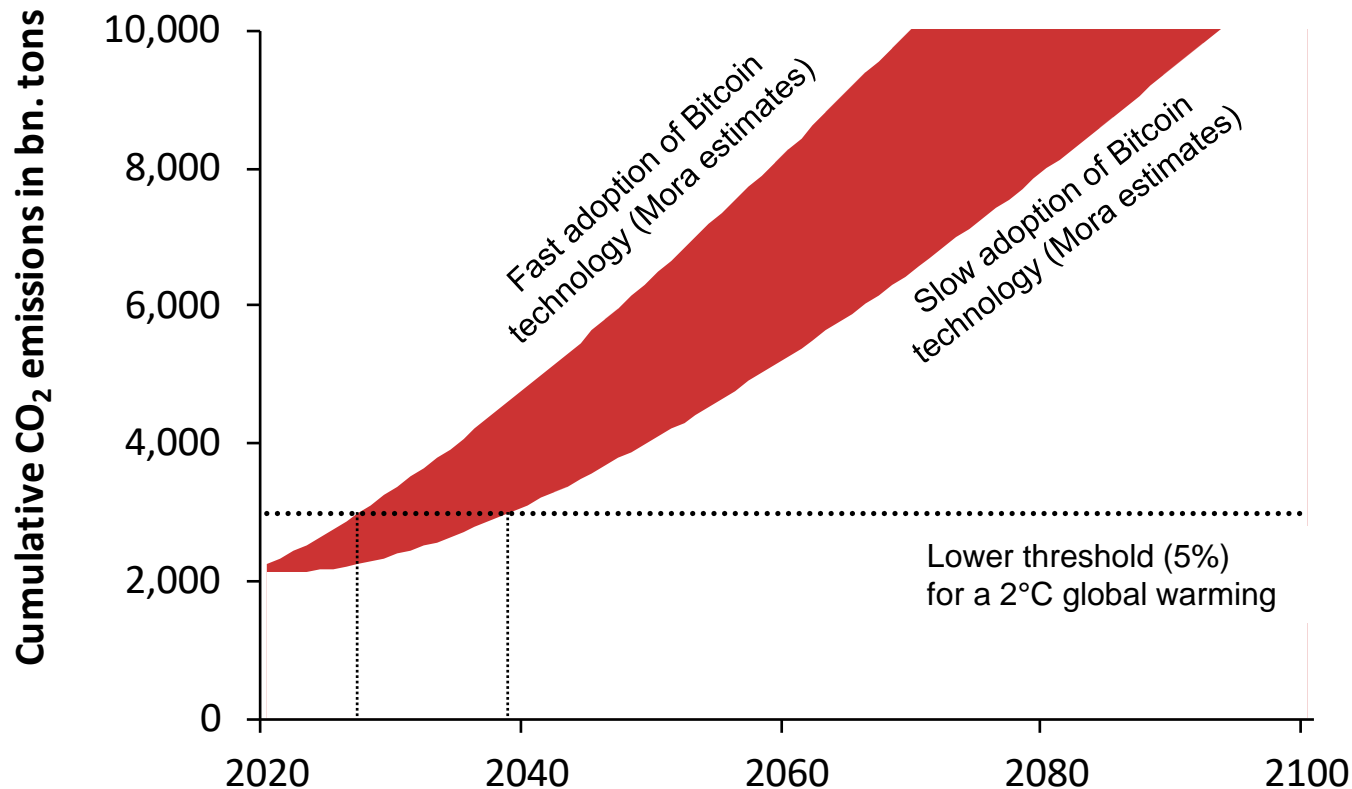
- ➤ Authors estimate market diffusion pathways for Bitcoin technology
- ➤ Slow diffusion: Bitcoin emissions alone cross 2°C threshold within 22 years
- ➤ Fast diffusion: Bitcoin emissions alone cross 2°C threshold within 11 years
- ➤ Median diffusion: Bitcoin emissions alone cross 2°C threshold within 16 years

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Methodology of Mora et al. (2018)

1) Estimation of electricity consumption of Bitcoin mining for the base year 2017

2) Conversion of estimated electricity consumption in 2017 into CO_2 emissions

3) Projection of CO_2 emission estimates for base year 2017 into the future until 2100

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Could Bitcoin emissions push global warming above 2 °C?

Lars Dittmar ✉ & Aaron Praktiknjo ✉

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Estimation of Bitcoin electricity consumption in 2017

Electricity 2017 → **62** → Bitcoins 2017

Mining devices
(Ø energy intensity 2.15 J/GHash)
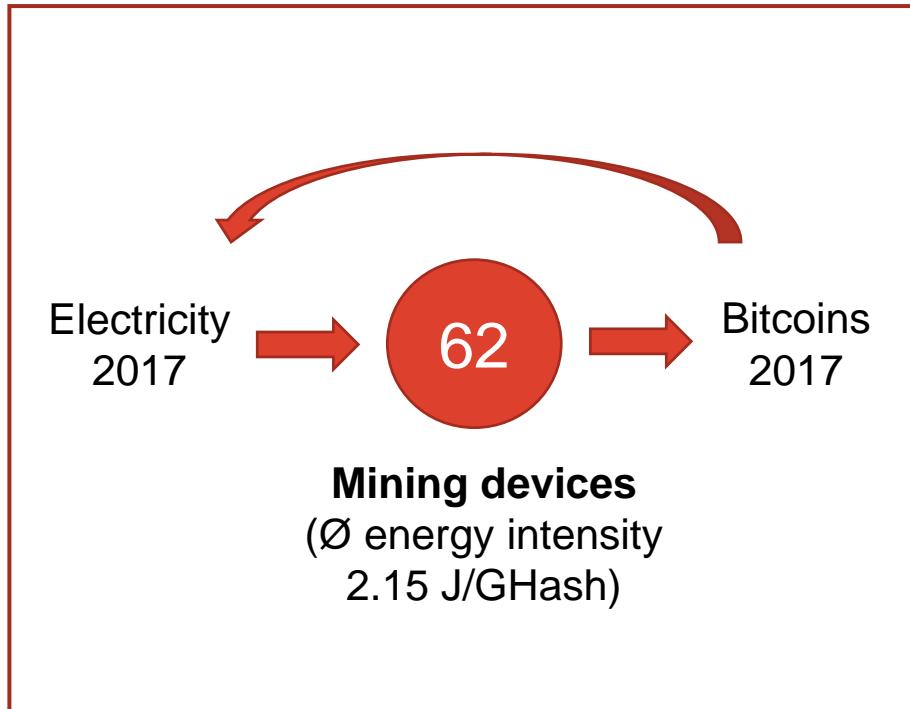
- ➢ Mora et al. (2018) compile a list of 62 mining devices including these devices' energy intensities

- ➢ Assumption that all Bitcoins mined in 2017 were randomly mined on one of these 62 devices

- ➢ Estimation of 114 TWh electricity consumption in 2017

- ➢ ~1/5 of Germany's or ~2x of Singapore's electricity consumption

- ➢ ~10x of our estimates for Bitcoin electricity consumption in 2017

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Underestimation of energy efficiency of Bitcoin hardware

Energy intensity in J/GHash
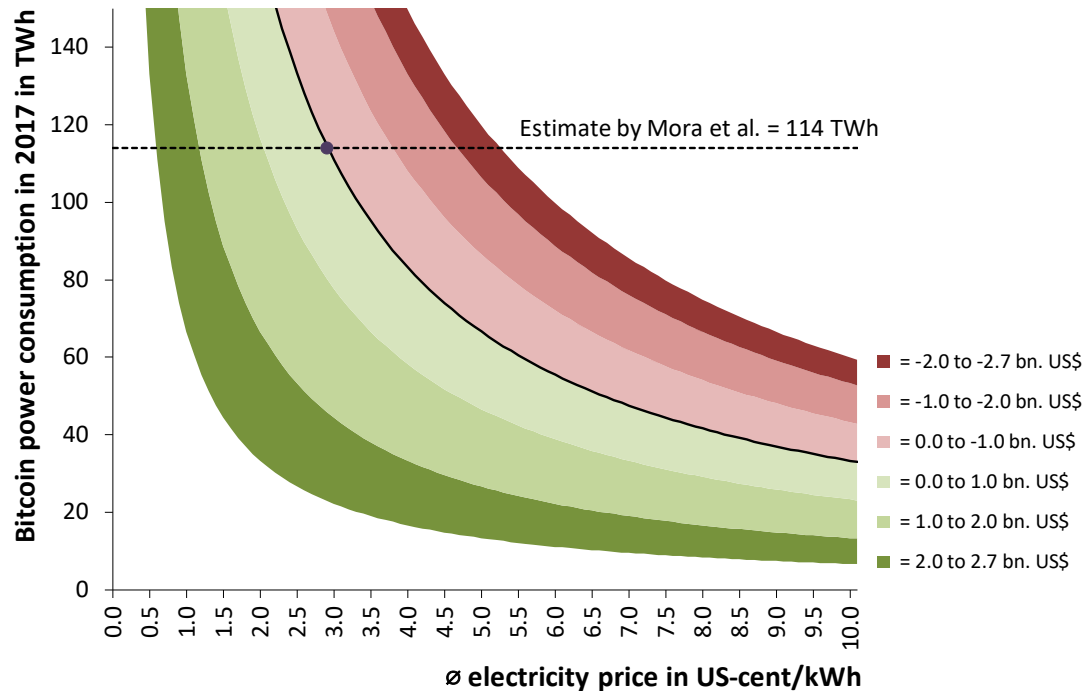(logarithmic scale)
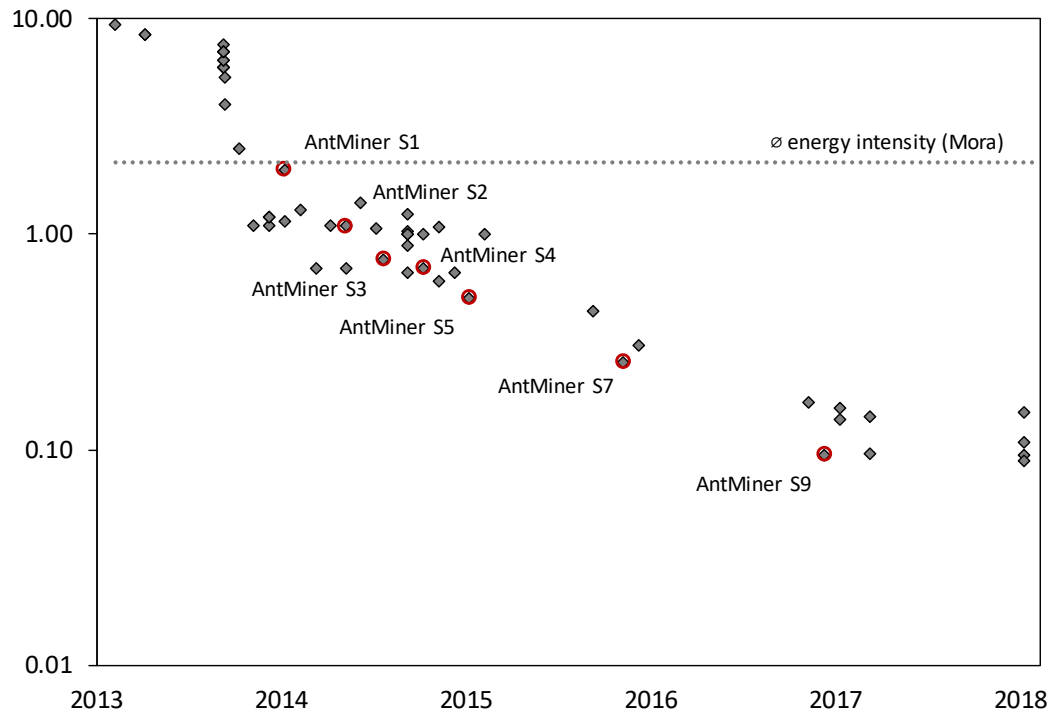
- ➤ Exponential improvement in energy efficiency for Bitcoin mining hardware

- ➤ AntMiner S1 from Bitmain released in 12/2013 with 2.00 J/GHash

- ➤ AntMiner S9 released in 12/2016 with 0.10 J/GHash

- ➤ The hardware list of Mora et al. (2018) contains many relatively old devices with high energy intensities
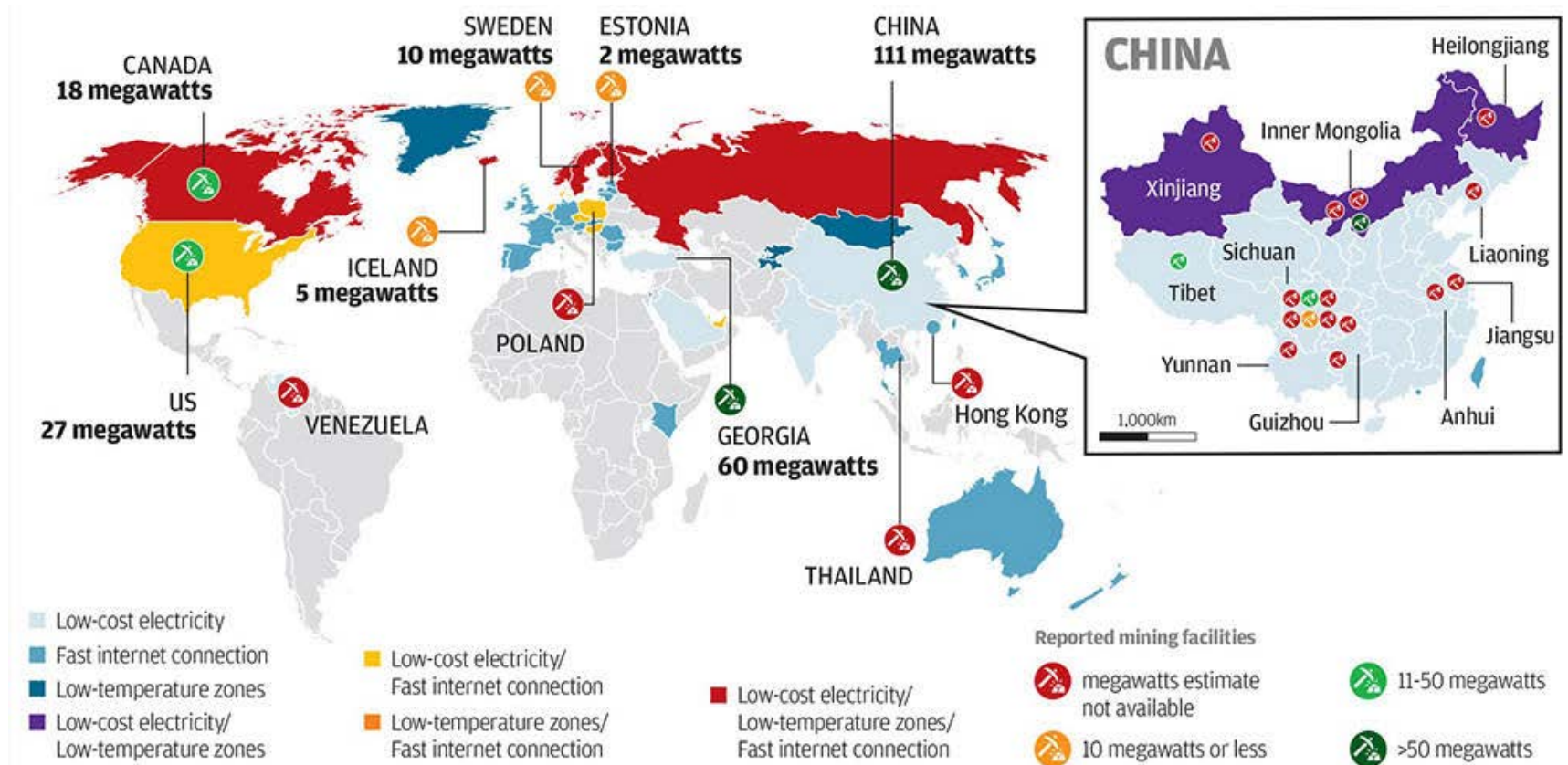
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Economics of Bitcoin mining and Bitcoin electricity consumption

Contribution margin = Revenues - Variable cost

Bitcoin power consumption in 2017 in TWh (y-axis)

Estimate by Mora et al. = 114 TWh

ø electricity price in US-cent/kWh (x-axis)

Legend:
- ■ = -2.0 to -2.7 bn. US$
- ■ = -1.0 to -2.0 bn. US$
- ■ = 0.0 to -1.0 bn. US$
- ■ = 0.0 to 1.0 bn. US$
- ■ = 1.0 to 2.0 bn. US$
- ■ = 2.0 to 2.7 bn. US$

➤ Revenues are awarded Bitcoins multiplied by Bitcoin price

➤ Variable cost are expenditures for electricity

➤ Bitcoin revenues in 2017 reported with ~3.3 bn. USD

➤ Estimated 114 TWh imply prices of <3 US-ct/kWh for positive contribution margins

➤ Community assumes electricity prices of ~5 US-ct/kWh

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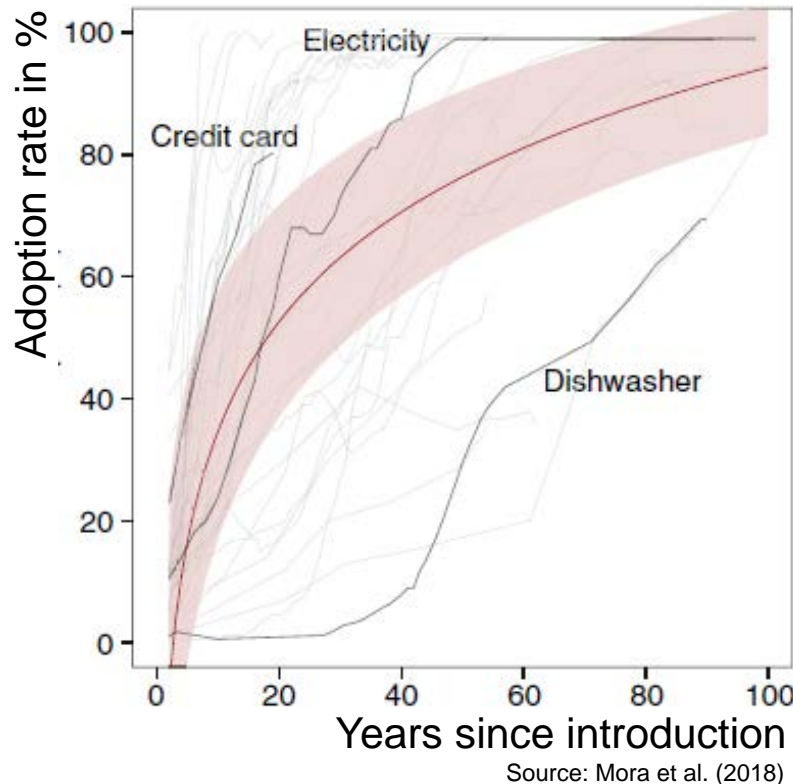E.ON Energy Research Center | RWTH AACHEN UNIVERSITY

Geographical distribution of Bitcoin mining and carbon emissions

Source: Hileman and Rauchs (2017)

- ➢ A large share of Bitcoin mining activities originates in China
- ➢ Mora et al. (2018) estimate an average emission factor of 605 g/kWh
- ➢ The estimated 114 TWh translate to 69 bn. tons of CO_2 emissions in 2017

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Projections of Bitcoin market diffusion until 2100

Source: Mora et al. (2018)

> Mora et al. (2018) analyze diffusion patterns of 40 broadly adopted technologies

> Among them are automobiles, TVs, PCs, credit cards, refrigerators, radios, etc.

> Assumption that Bitcoin will follow a similar pattern with slow, median, and fast diffusion

> Eventually, Bitcoin is estimated to replace all of today's ~314.2 bn. annual cashless transactions

> Projection of emission estimates for 2017 into the future by scaling with the number of transactions

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Projections of emissions until 2100 based on estimations for 2017

CO_2 emission factor for electricity
in China in g/kWh
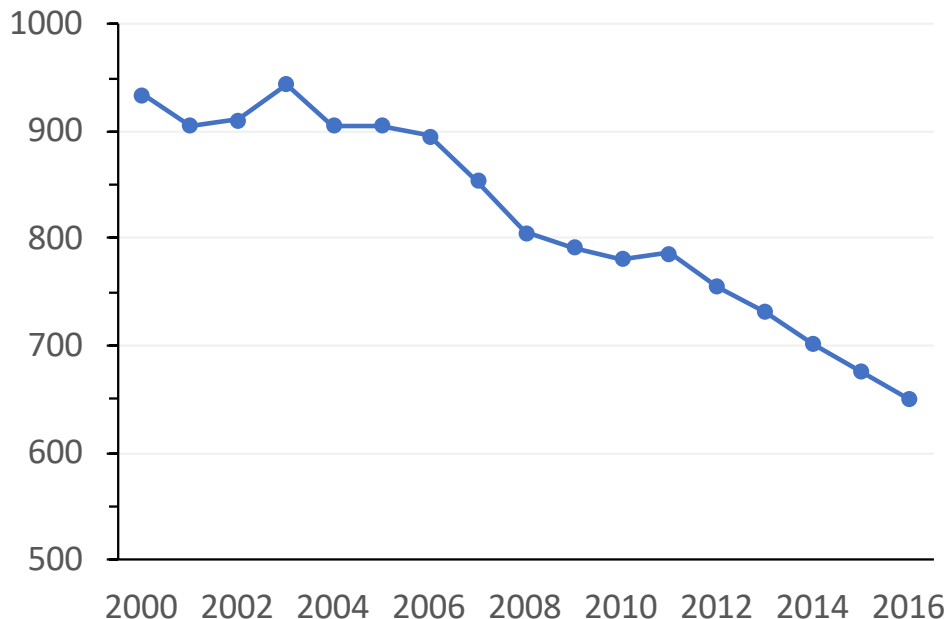
- ➢ Mora et al. (2018) assume energy efficiency of Bitcoin mining hardware to remain constant over the next 80 years at 2.15 J/GHash

- ➢ But on average, energy efficiency of mining hardware has been doubling every 10 months over the last five years

- ➢ Also, emission factors assumed to remain constant until 2100 at 605 g/kWh

- ➢ China's electricity emission factor decreased by 2.2 % p.a. on average over the last 16 years

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Maximum limitation of number of Bitcoin transactions

#	G5J97YP
Content	Transaction 1
	Transaction 2
	…
	…

> ➤ Average duration to mine a new Bitcoin block is 10 minutes (so-called block interval)

> ➤ The size of a Bitcoin block equals 1 MB (effectively 4 MB after SegWit upgrade)

> ➤ ~314.2 bn. annual transactions are equivalent to ~6 mn. transactions per 10 minutes

> ➤ This exceeds current Bitcoin transaction limits by a factor of ~500

> ➤ Number of transactions could be increased by either increasing block size even further or decreasing block interval

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Bitcoin mining and electricity consumption

Difficulty

=

Block interval

x

Computing power

x

2^{32}

➤ Besides the energy efficiency of the hardware, Bitcoin's energy consumption depends on the number of hashes performed to mine a block

➤ The average block interval of 10 minutes is hold constant through an automatic adjustment of the difficulty to solve a block (i.e. expected required number of hashes)

➤ Depending on the network's current total computing power, difficulty increases or decreases

➤ In any case, Bitcoin energy consumption does not scale with the number of transactions

➤ Increasing number of transactions actually decreases energy consumption per transaction

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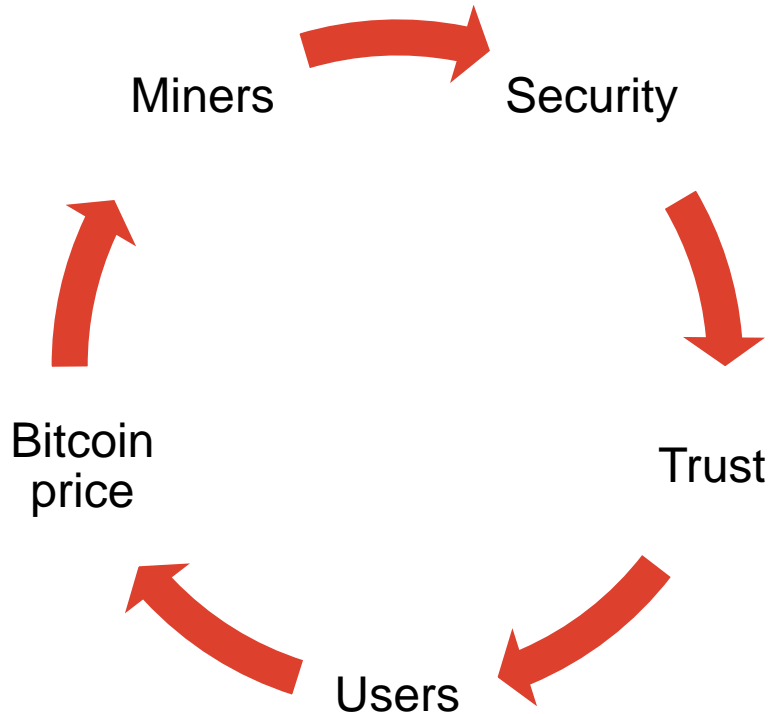# Medium term estimates of Bitcoin energy consumption

- ➤ In their median scenario, Mora et al. (2018) anticipate a Bitcoin adoption of ~16.8% within five years

- ➤ This corresponds to an implicit Bitcoin electricity consumption of ~57,800 TWh in that year

- ➤ In 2017, global electricity consumption was reported at ~22,200 TWh (a growth of ~360% within five years)

- ➤ Such an increase (practically unfeasible) would lead to cost explosions of electricity which would dampen demand from Bitcoin mining

- ➤ The IEA (2018) estimates an increase of global electricity production of ~60% – but until 2040

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Conclusion

- ➢ Bitcoin mining is certainly energy intensive

- ➢ But estimates and projections are often overestimated

- ➢ Serious analyses account for systemic impacts (feedback loops)

- ➢ Energy intensity of decentralized blockchain ensures security ("it's not a bug, it's a feature")

- ➢ More research into techno-economic ecosystems of blockchain is required

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Thank you for your attention!