Academy of Mathematics and Systems Science
Chinese Academy of Sciences

中国科学院大学
School of Economics and Management, UCAS

nature COMMUNICATIONS

Policy assessments for the carbon emission flows and sustainability of Bitcoin blockchain operation in China

Shangrong Jiang

School of Economics and Management, University of Chinese Academy of Sciences

Center for Forecasting Science, Chinese Academy of Sciences

Email: jiangshangrong18@mails.ucas.ac.cn

May 13, 2021

Outline

Outline

Abstract

- By a simulation-based Bitcoin blockchain carbon emission model, we find that without any policy interventions, the annual energy consumption of the Bitcoin blockchain in China is expected to peak in 2024 at 296.59 Twh and generate 130.50 million metric tons of carbon emission correspondingly.

- Internationally, this emission output would exceed the total annualized greenhouse gas emission output of the Czech Republic and Qatar. Domestically, it ranks in the top 10 among 182 cities and 42 industrial sectors in China.

- We show that moving away from the current punitive carbon tax policy to a site regulation policy which induces changes in the energy consumption structure of the mining activities is more effective in limiting carbon emission of Bitcoin blockchain operation.

Outline

Background

- As Bitcoin attracted considerable amount of attention in recent years, its underlying core mechanism, namely blockchain technology, has also quickly gained popularity.

- Due to its key characteristics such as decentralization, auditability and anonymity, blockchain is widely regarded as one of the most promising and attractive technologies for a variety of industries, such as supply chain finance, production operations management, logistics management and the Internet of Things (IoT).

- Despite its promises and attractiveness, its first application in the actual operation of the Bitcoin network indicates that there exists a non-negligible energy and carbon emission drawback with the current consensus algorithm.

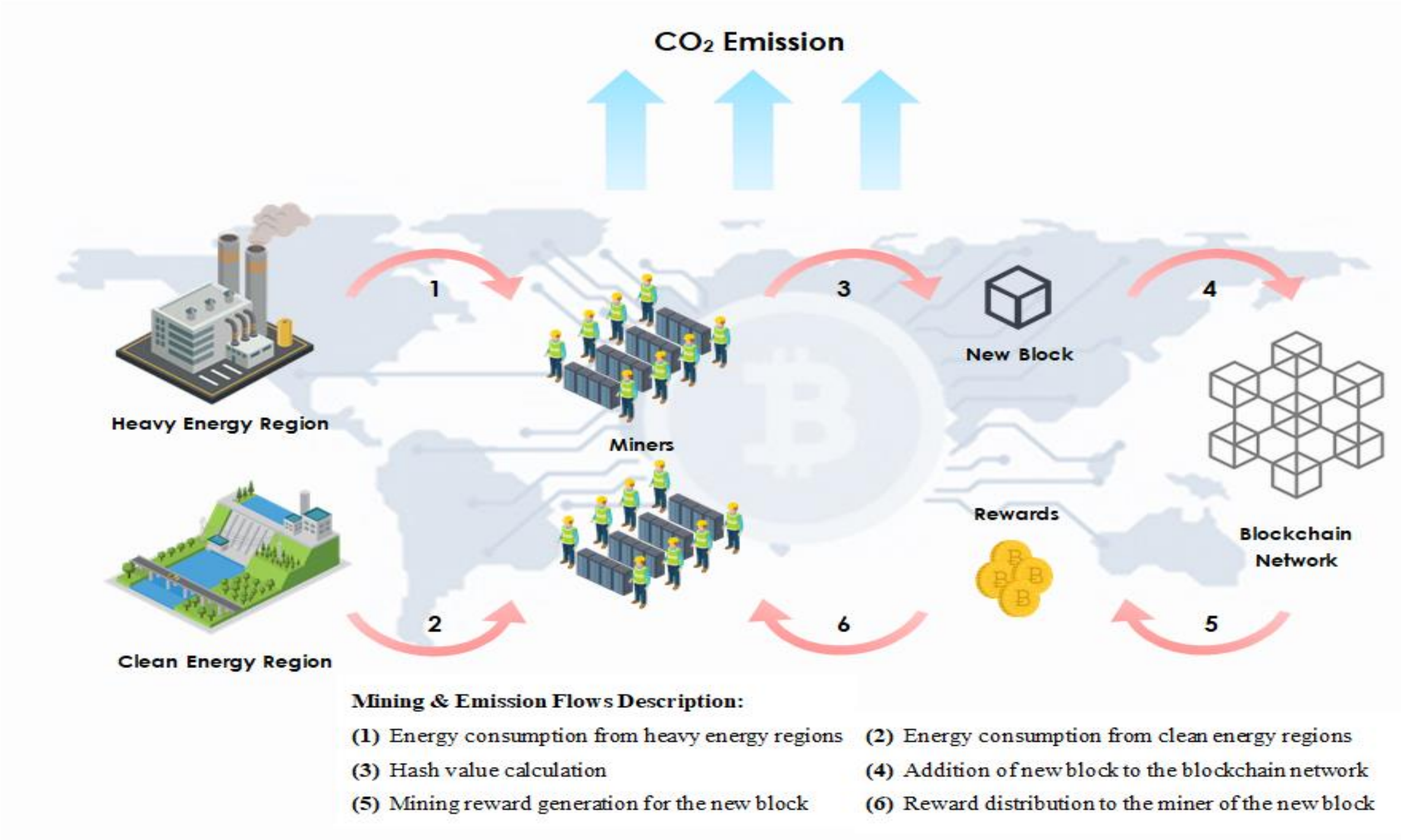
Methods & contributions

- The system dynamics (SD) based model is widely introduced for carbon emission flows estimation of a specific area or industry.

- SD modelling has two main advantages: first, by combining the feedback loops of stock and flow parameters, SD is able to capture and reproduce the endogenous dynamics of complex system elements, which enables the simulation and estimation of specific industry operations. In addition, since the SD based model is focused on disequilibrium dynamics of the complex system, intended policies can be adjusted for scenario policy effectiveness evaluation.

- Consequently, based on system dynamics modeling, we develop the Bitcoin blockchain carbon emission model (BBCE) to assess the carbon emission flows of the Bitcoin network operation in China under different scenarios.

Proof-of-Work algorithm



Supplementary Fig. 2 | Carbon footprint for Proof-of-Work algorithm of Bitcoin blockchain. The PoW validation process of Bitcoin blockchain involves miners solving a cryptographic puzzle to adjust the nonce and generate a hash value lower than or equal to a certain target value, where miners earn 6.25 Bitcoin currently as new block reward. The mining and calculation process of Bitcoin blockchain requires steadily growing amount of energy due to the fierce competition between miners. Both coal-based and hydro-based energy consumed by Bitcoin miners are collected to formulate the carbon emission flows of the whole Bitcoin blockchain. The mining area distribution of Bitcoin blockchain is obtained from https://btc.com/stats

Outline

The problem of Bitcoin mining in China

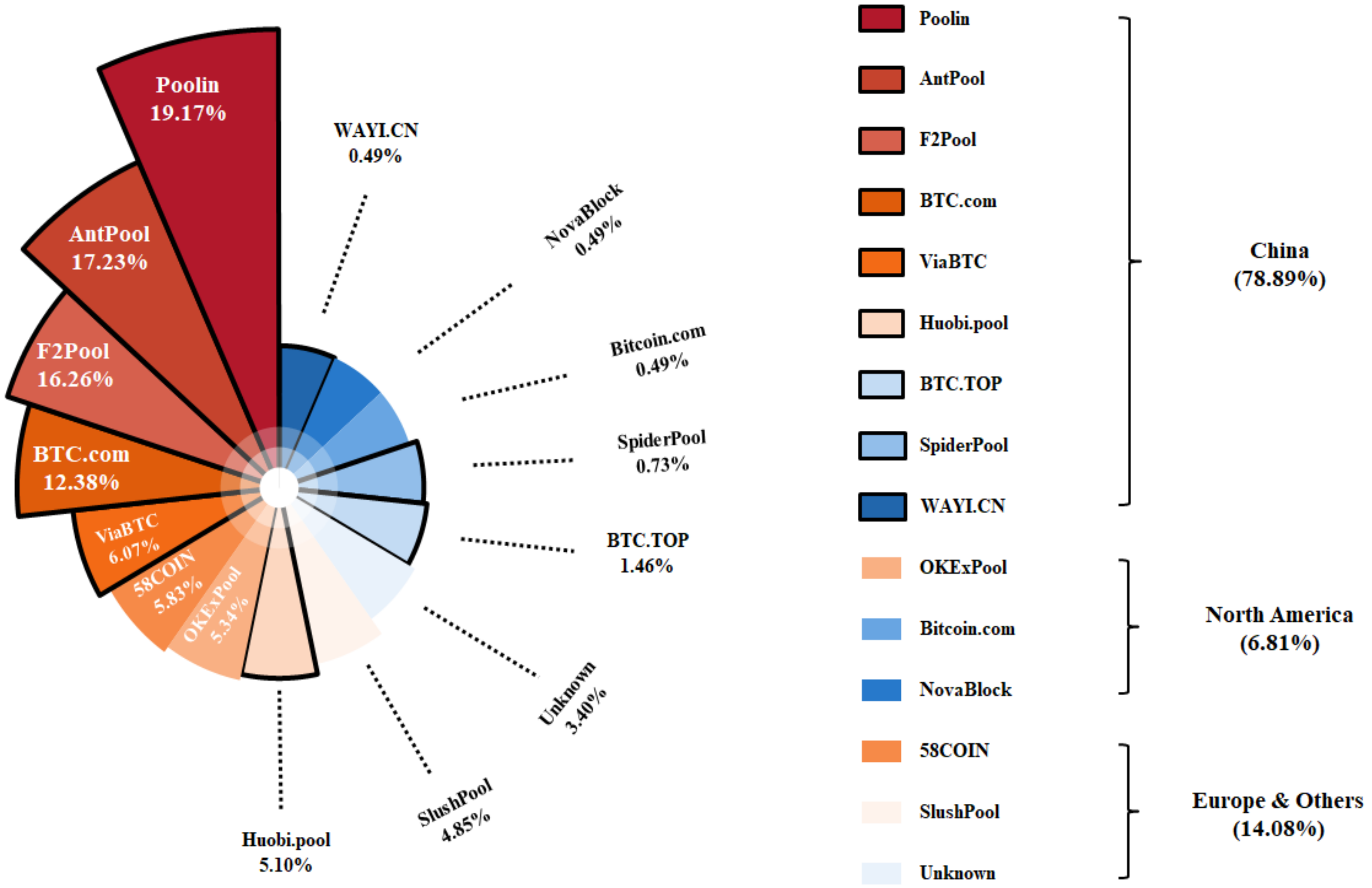


Fig. 1 | Mining pool distributions of Bitcoin blockchain. As of April 2020, China accounts for more than 75% of Bitcoin blockchain operation around the world. Some rural areas in China are considered as the ideal destination for Bitcoin mining mainly due to the cheap electricity price and large undeveloped land for pool construction. The mining pool statistics is obtained from https://btc.com/stats.

Policy parameter settings

Table 1 | Scenario parameter settings

Scenarios	Measures	Market access	Miner site selection	Carbon tax
Benchmark (BM)	Baseline policy intervention	100%	40%	2
Market access (MA)	Raise the market access standards for Bitcoin miner efficiency	50%	40%	2
Site regulation (SR)	Strict regulation on Bitcoin industry in the coal-based energy region	100%	20%	2
Carbon tax (CT)	Extra Punitive carbon tax on Bitcoin mining	100%	40%	4

Note: Exogenous auxiliary parameters are introduced to assess the carbon emission flows under different Bitcoin policy measures. In terms of variable settings, three main parameters are chosen as the scenario factors in the proposed BBCE model, including market access (MA), miner site regulation (SR) and carbon tax (CT).

We consider three main Bitcoin policies conducted at different stages of the Bitcoin mining industry, which then formulates the four scenario assessments for Bitcoin blockchain carbon emission flows (in Table 1).

Utilizing the above scenarios, carbon emission flows and energy consumptions of Bitcoin blockchain are assessed, the carbon and energy reduction effectiveness of different policies are evaluated in BBCE simulations from the period of 2014 to 2030.

Annualized scenario simulation results

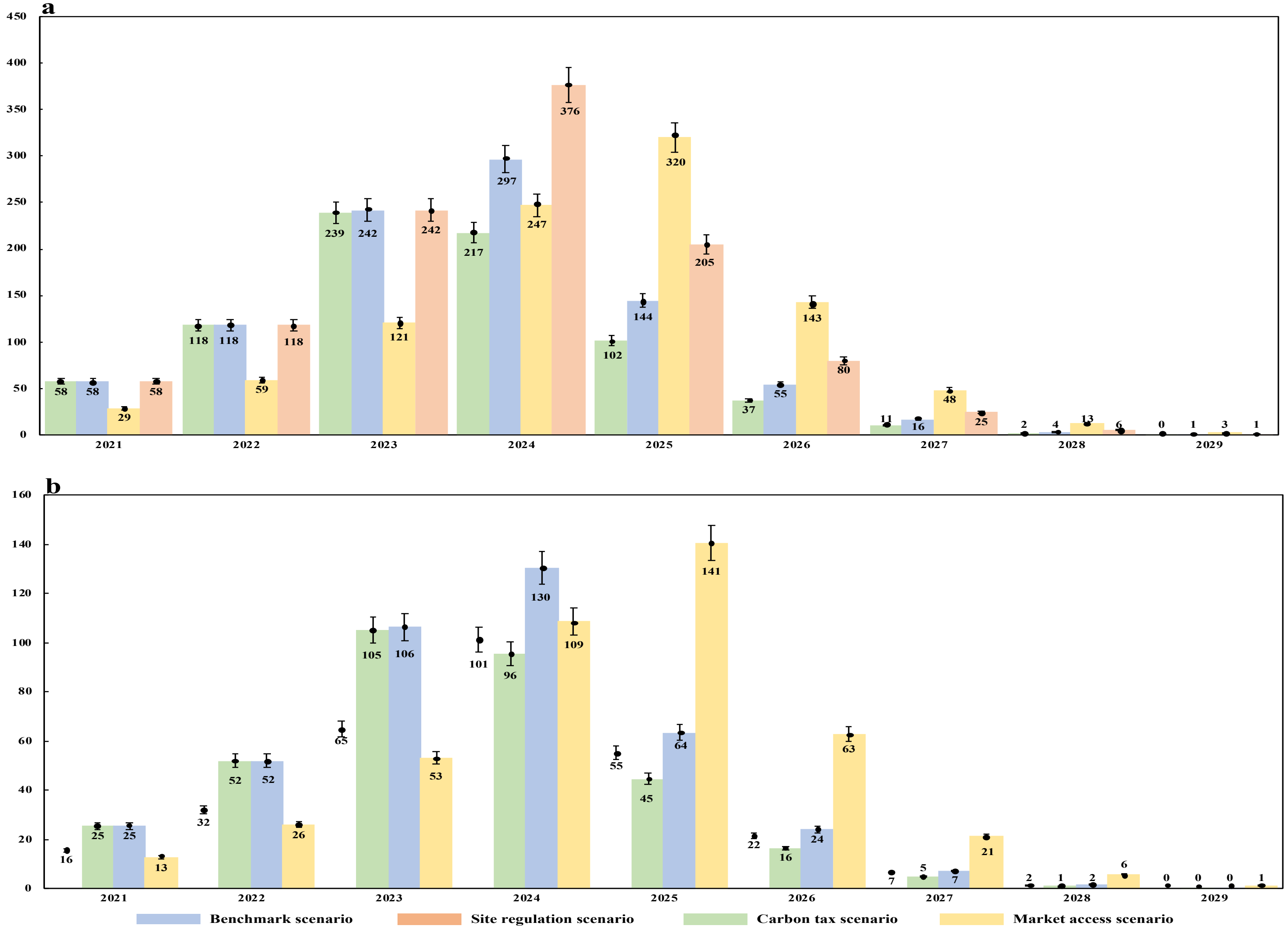
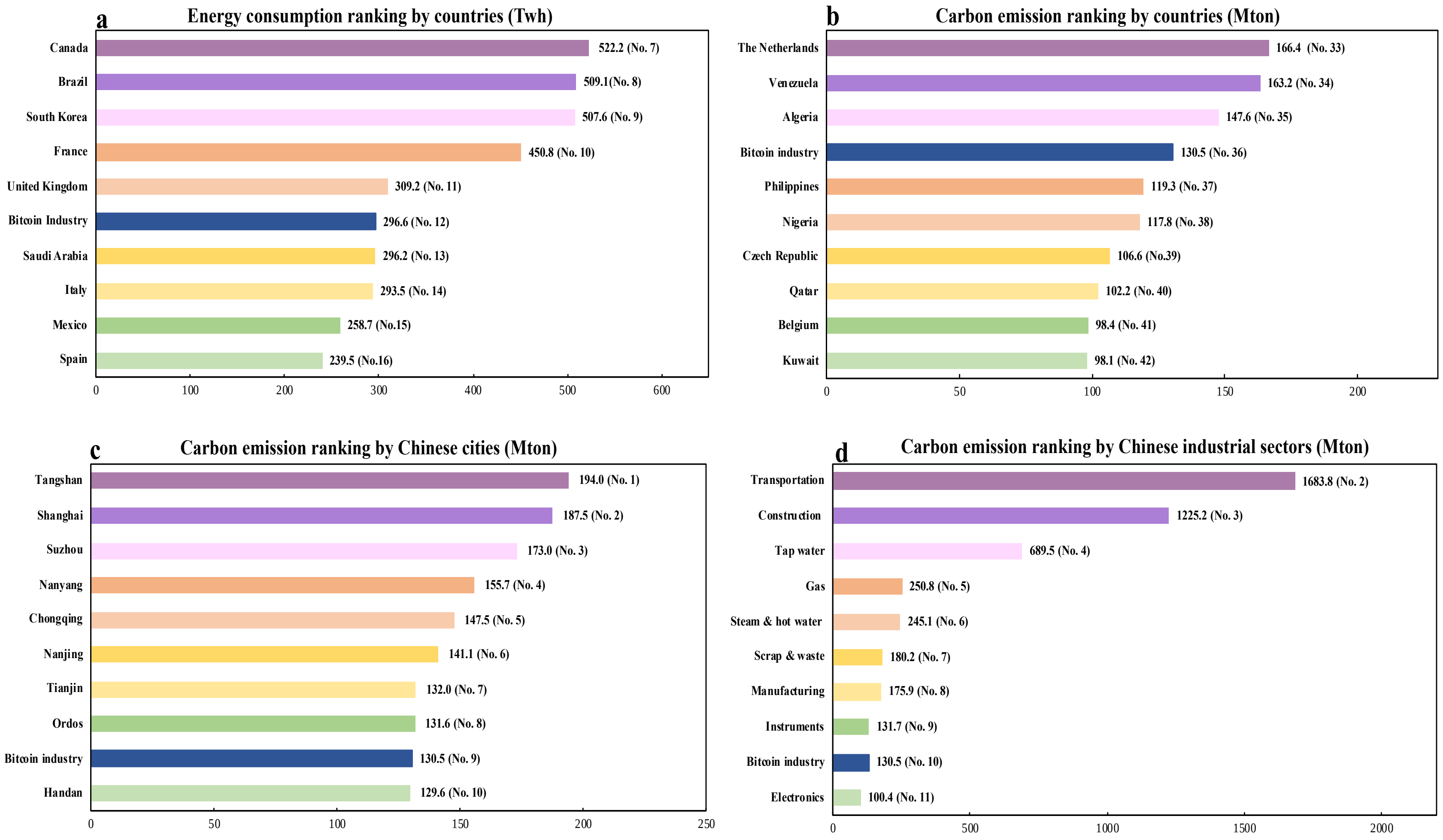


Fig. 2 | Estimated annualized scenario simulation results. Estimated annualized energy consumption (a) and carbon emission flows (b) of Bitcoin operation in China are generated through monthly simulation results of BBCE modelling from 2021 to 2030. The blue, red, yellow and green bars in **a** and **b** indicate the annual energy consumption and carbon emission flows of Chinese Bitcoin industry in Benchmark, Site regulation, Market access and Carbon tax scenario, respectively. Each data is presented as mean values +/- SEM based on 95% confidence intervals calculated by two-tailed t-tests ($p<0.05$). n=204 emission observations.

Emission comparisons



The estimated Bitcoin carbon emission in China exceeds the total greenhouse emission of the Czech Republic and Qatar in 2016, ranking it 36th worldwide and ranks in the top 10 among 182 Chinese prefecture-level cities and 42 major industrial sectors.

Fig. 3 | Bitcoin industry energy consumption and carbon emission comparisons. In Fig. 3, the peak energy consumption and carbon emission of Bitcoin industry are compared to annual energy consumption and ranking by countries (a), carbon emission and ranking by countries (b), the carbon emission by Chinese cities (c) and industrial sectors (d)

Carbon policy effectiveness evaluation

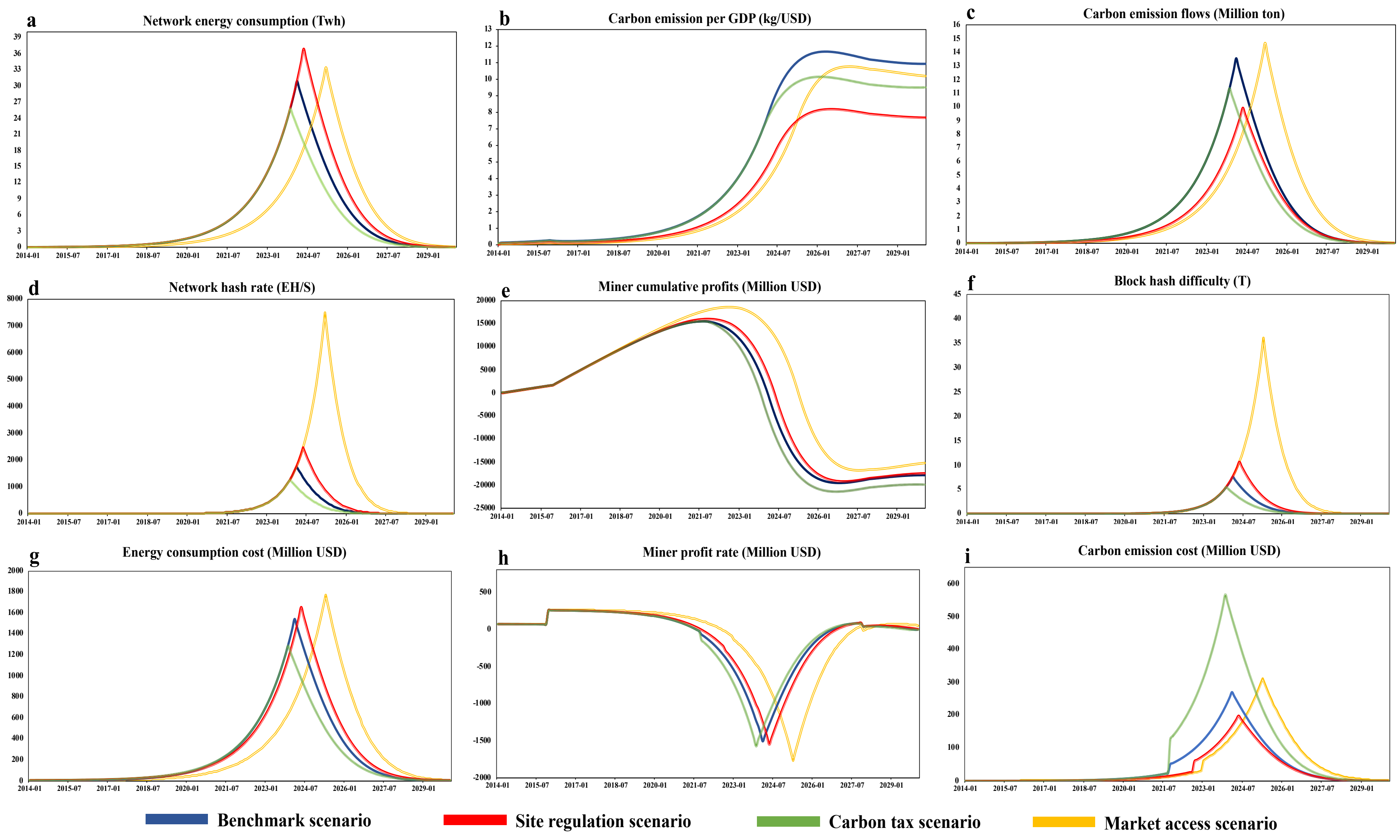


Fig. 4 | BBCE scenario assessment comparisons. a-i, monthly network energy consumption (a), carbon emission per GDP (b), carbon emission flows (c), network hash rate (d), miner cumulative profits (e), block hash difficulty (f), energy consumption cost (g), miner profit rate (h) and carbon emission cost (i) under each intended policy are simulated and calculated by BBCE framework. Based on the regressed parameters of the BBCE model, the whole sample timesteps of network carbon emission assessment cover the period from January 2014 to January 2030.

Carbon policy effectiveness evaluation

- Although the MA scenario enhances the market access standard to increase Bitcoin miners' efficiencies, it is regarded as an emission-prompted policy rather than an emission-reduced policy based on the simulation results.

- In the MA scenario, we observe the phenomenon of "Incentive Effects" proposed by previous works, which is identified in other fields of industrial policies, such as monetary policies, transportation regulations and firm investment strategies.

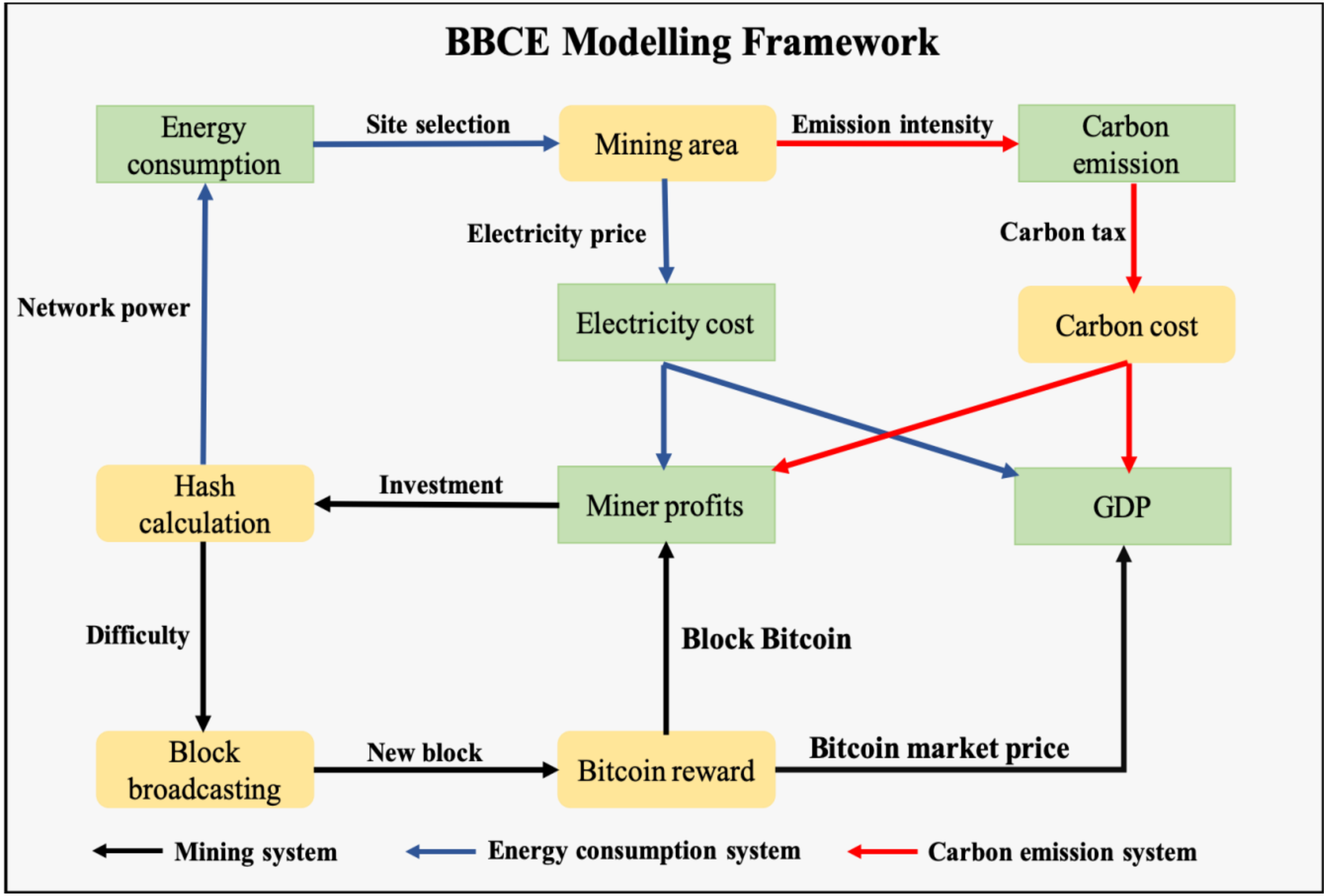
- The results of the MA scenario indicate that market-related policy is likely to be less effective in dealing with high carbon emission behaviors of the Bitcoin blockchain operations.

Carbon policy effectiveness evaluation

- The carbon taxation policy is widely acknowledged as the most effective and most commonly implemented policy on carbon emission reduction. However, the simulation results of the CT scenario indicate that carbon tax only provides limited effectiveness for the Bitcoin industry.
- The carbon emission patterns of the CT scenario are consistent with the BM scenario until Bitcoin miners are aware that their mining profitabilities are affected by the punitive carbon tax on Bitcoin mining.
- On the contrary, the evidence from the SR scenario shows that the carbon-related policies are able to provide negative feedbacks for the carbon emissions of Bitcoin blockchain operations.

Outline

Framework



The BBCE model consists of three interacting subsystems: Bitcoin blockchain mining and transaction subsystem, Bitcoin blockchain energy consumption subsystem and Bitcoin blockchain carbon emission subsystem.

Mining and transaction subsystem

- To increase the probability of mining a new block and getting rewarded, the mining hardware will be updated continuously and invested by network participants for higher hash rate, which would cause the hash rate of the whole network to rise. In order to maintain the constant 10-minute per new block generation process, the difficulty of generating a new block is adjusted based on the current hash rate of the whole Bitcoin network.
- Overall, the profit of Bitcoin mining can be calculated by subtracting the total cost of energy consumption and carbon emissions from block reward and transaction fees. Miners will stop investing and updating mining hardware in China when the total cost exceeds the profit rate. Consequently, the whole network hash rate receives a negative feedback due to the investment intensity reductions.

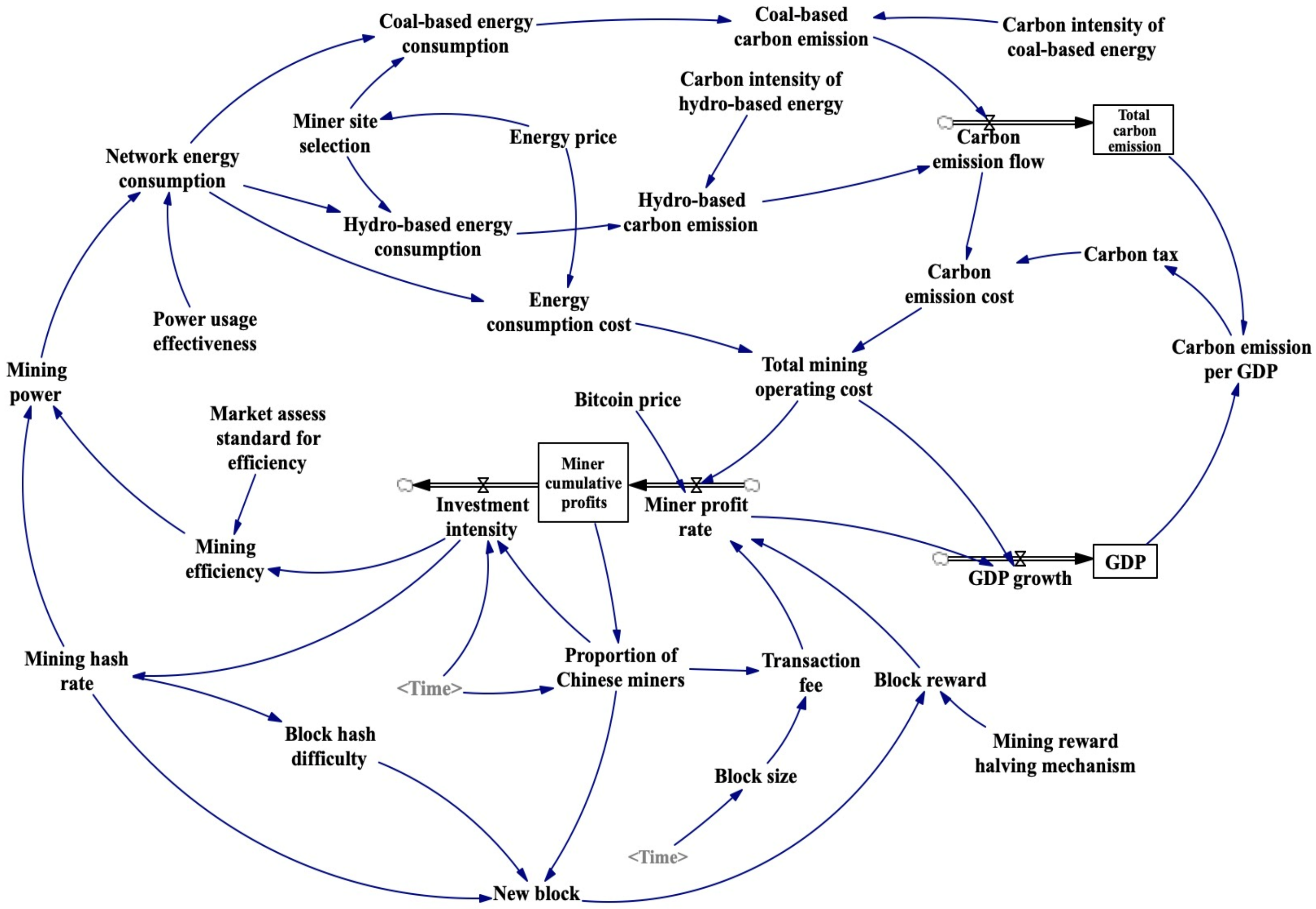
Energy consumption subsystem

- The network mining power is determined by two factors: first, the network hash rate positively accounts for the mining power increase in Bitcoin network when high hash rate miners are invested.
- However, the updated Bitcoin miners also attempt to reduce the energy consumption per hash, i.e., improve the efficiency of Bitcoin mining process, which helps to reduce the network mining power consumption.
- In term of the energy consumption of the whole network, the power usage effectiveness is introduced to illustrate the energy consumption efficiency of Bitcoin blockchain as suggested by Stoll.
- Finally, the network energy cost of Bitcoin mining process is determined by the network energy consumption and average electricity price, which further influences the dynamics behaviors of Bitcoin miner's investment.

Carbon emission subsystem

- The proposed BBCE model collects the carbon footprint of Bitcoin miners in both coal-based and hydro-based energy regions to formulate the overall carbon emission flows of the whole Bitcoin blockchain in China.
- In comparison to miners located in hydro-rich regions, miners located in coal-based regions generate more carbon emission flows under the similar mining techniques and energy usage efficiency due to the higher carbon intensity of coal-based energy
- The level variable GDP consists of Bitcoin miner's profit rate and total cost, which suggests the productivity of the Bitcoin blockchain.
- It also serves as an auxiliary factor to generate the carbon emission per GDP in our model, which provides guidance for policy makers to implement punitive carbon taxation on Bitcoin industry.

Framework



Supplementary Fig. 1 | Flow diagram of BBCE modelling. Parameters of the Bitcoin blockchain carbon emission system in Supplementary Fig. 1 are quantified in BBCE simulations, which are suggested by the feedback loops of Bitcoin blockchain. The whole quantitative relationships of BBCE parameters are demonstrated in Supplementary Methods.

Parameterizations

- Our BBCE model has been constructed in Vensim software (PLE version 8.2.1).
- The time-related Bitcoin blockchain data are obtained from www.btc.com, including network hash rate, block size, transaction fee and difficulty. In addition, the auxiliary parameters and macroenvironment variables for network carbon emission flows assessment are set and considered through various guidelines.
- The monthly historical data of Bitcoin blockchain are utilized for regression and simulation from the period of January 2014 to January 2020 through Stata software (version 14.1). Based on the regressed parameters, the whole sample timesteps of network carbon emission assessment cover the period from January 2014 to January 2030 in this study, which is available for scenario investigations under different Bitcoin policies.

Parameterizations

$Investment\ intensity = 40.51 \times Time \times Proportion\ of\ Chinese\ miners$ (1)

$Proportion\ of\ Chinese\ miners = IF\ THEN\ ELSE\ (Miner\ cumulative\ Profits < 0, 0.7 - 0.01 \times Time, 0.7)$ (2)

$Transaction\ fee = 0.115 \times Block\ size \times Proportion$ (3)

$Block\ size = e^{7.22+0.0215 \times Time}$ (4)

$Block\ reward = New\ block \times Mining\ reward\ halving\ mechanism$ (5)

$Bitcoin\ price = 1000 + STEP\ (6000,24) + STEP\ (6000,72) + STEP\ (12000,120)$ (6)

$Miner\ profit\ rate = Bitcoin\ price * (Mining\ reward\ halving\ mechanism + Transactionfee) - Total\ mining\ operating\ cost$ (7)

$Miner\ cumulative\ profits\ (t) = \int_0^t (Miner\ profit\ rate - Investment\ intensity) dt$ (8)

$GDP\ growth = Miner\ profit\ rate + Total\ mining\ operating\ cost$ (9)

$GDP(t) = \int_0^t GDP\ growth\ dt$ (10)

$Mining\ hash\ rate = 0.7 \times e^{0.0039 \times Investment\ intensity + 8.16}$ (11)

$Mining\ efficiency = e^{9.3 - 0.0018 \times Investment\ intensity \times Market\ access}$ (12)

$Mining\ power = Mining\ hash\ rate \times Mining\ efficiency$ (13)

$Network\ energy\ consumption = 0.7315 \times Mining\ power \times Power\ usage\ effectiveness$

$Energy\ consumption\ cost = 0.05 \times Network\ energy\ consumption$ (15)

$Total\ mining\ operating\ cost = Energy\ consumption\ cost + Carbon\ emission\ cost$ (16)

Coal-based $energy\ consumption = Miner\ site\ selection \times Network\ energy\ consumption$ (17)

Hydro-based $energy\ consumption = (1 - Miner\ site\ selection) \times Network\ energy\ consumption$ (18)

Coal-based $energy\ carbon\ emission =$ *Coal-based* $energy\ consumption \times Carbon\ intensity\ of\ coal\text{-}based\ energy$ (19)

Hydro-based $energy\ carbon\ emission =$ *Hydro-based* $energy\ consumption \times Carbon\ intensity\ of\ hydro\text{-}based\ energy$ (20)

$Total\ carbon\ emission\ (t) = \int_0^t Carbon\ emission\ flow\ dt$ (21)

$Carbon\ emission\ per\ GDP = Carbon\ emission/GDP$ (22)

$Carbontax = 0.01 \times IF\ THEN\ ELSE\ (Carbon\ emission\ perGDP > 2, 2, 1)$ (23)

Carbon emission flow = *Coal-based* $energy\ carbon\ emission +$ *Hydro-based* $energy\ carbon\ emission$ (24)

Carbon emission *cost* = *Carbon tax* ×*Carbon emission* flow (25)

Parameterizations

Supplementary Table 2 Initial value of auxiliary parameters in the BBCE model

Parameter	Value	Unit	Parameter	Value	Unit
Carbon tax	0.01	USD/kg	Market access standard for efficiency	100	%
Carbon intensity of coal-based energy	0.9	Kg/kwh	Power usage effectiveness	1.1	-
Carbon intensity of hydro-based energy	0.2	Kg/kwh	Miner site selection	40	%
Energy price	0.05	USD/kwh	Proportion of Chinese miners	70	%

The initial value of static parameters in BBCE model are shown in Supplementary Table 2, the actual values of the parameterizations adopted are reported in Supplementary Methods

Robustness

- In order to test the suitability and robustness of BBCE modelling system structures and behaviors, three model validation experiments are introduced and conducted in our study, i.e., the structural suitability tests (see Supplementary Fig. 3), reality and statistical tests (see Supplementary Fig. 4), and sensitivity analysis (see Supplementary Fig. 5).
- The model validation results indicate that the proposed BBCE model can effectively simulate the causal relationship and feedback loops of carbon emission system in Bitcoin industry, and the parameters in BBCE model have significant consistencies with actual Bitcoin operating time-series data.

Robustness

Model Assessment Results

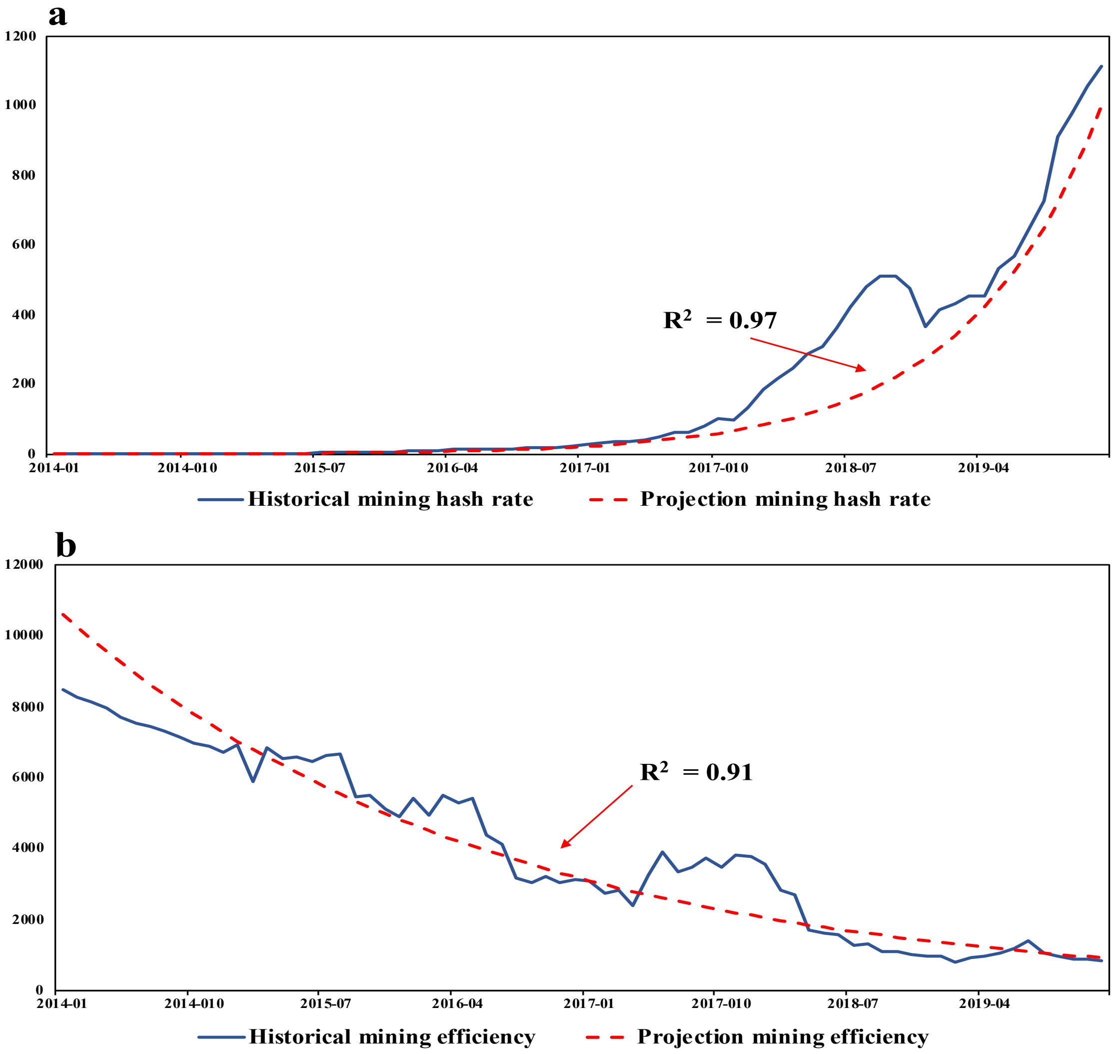
Model Information	Result
Total Number Of Variables	38
Total Number Of State Variables	3 (7.9%)
Total Number Of Stocks	3 (7.9%)
Total Number Of Feedback Loops No IVV (Maximum Length: 30) [3, 15]	17 (0|0|17)
Total Number Of Feedback Loops With IVV (Maximum Length: 30) [0, 0]	0 (0|0|0)
Total Number Of Causal Links	51 (0|0|51)
Total Number of Rate-to-rate Links	1
Number Of Units Used In The Model (Basic/Combined)	3/0
Total Number Of Equations Using Macros	0 (0.0%)
Variables With Source Information	0 (0.0%)
Dimensionless Unit Variables	17 (44.7%)
Function Sensitivity Parameters	0 (0.0%)
Data Lookup Tables	0 (0.0%)
Time Unit	Month
Initial Time	1
Final Time	204
Reported Time Interval	TIME STEP
Time Step	1
Model Is Fully Formulated	Yes

Warnings	Result
Variables Not In Any View	0 (0.0%)
Nonmonotonic Lookup Functions	0 (0.0%)
Cascading Lookup Functions	0 (0.0%)
Non-Zero End Sloped Lookup Functions	0 (0.0%)
Equations With If Then Else Functions	2 (5.3%)
Equations With Min Or Max Functions	0 (0.0%)
Equations With Step Pulse Or Related Functions	2 (5.3%)
Equations With Unit Errors Or Warnings	0 (0.0%)

Potential Omissions	Result
Unused Variables	0 (0.0%)
Supplementary Variables	0 (0.0%)
Supplementary Variables Being Used	0 (0.0%)
Complex Variable	1 (2.6%)
Complex Stock	0 (0.0%)

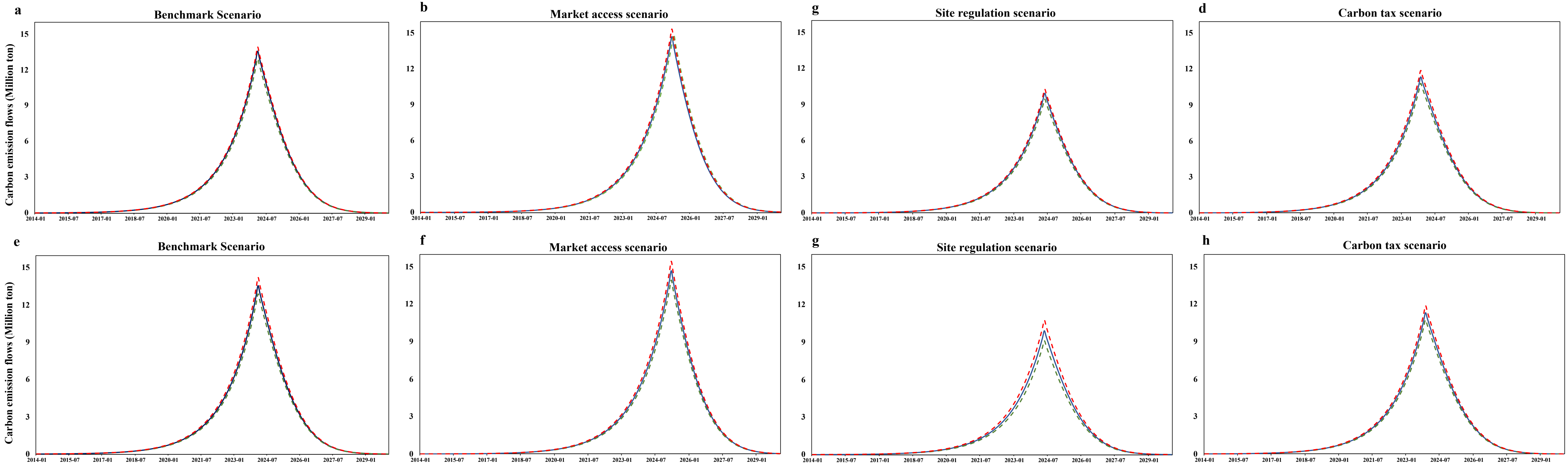
Supplementary Fig. 3 | Model assessment results of BBCE modelling. Based on the System Dynamics Model Documentation and Assessment Tool, this Figure presents the basic BBCE modelling assessment results. The whole assessment results are demonstrated in Supplementary Notes.

Robustness



Supplementary Fig. 4 | Reality and statistical test results. This Figure illustrates the historical and projected mining hash rate (a) and mining efficiency (b) comparison results based on the actual bitcoin time-series data. We introduce R2 to interpret the goodness of fit and parameter consistencies of BBCE modelling.

Robustness



Supplementary Fig. 5 | Sensitivity analysis results. (a)-(d) provide alternative initial parameter settings of power usage efficiency (PUE) in each scenario and comparisons of the estimated carbon emission flows under different parameterizations. (e)-(h) provides alternatives initial proportions of Chinese Bitcoin servers located in coal-based region. The red dash lines in (a)-(d) denote parameterization of PUE at 1.15 and the green dash lines at 1.05. The red dash lines in (e)-(h) denote parameterization of proportions of Chinese Bitcoin servers located in coal-based region at 43% (at 23% in Site Regulation scenario) and the green dash lines at 37% (at 17% in Site Regulation scenario). The blue solid lines from (a)-(d) denote the parameterizations of PUE at 1.1 in each scenario, and that of (e)-(h) denote the parameterizations of proportions of Chinese Bitcoin servers located in coal-based region at 40% in each scenario (20% in Site regulation scenario, which are utilized in the actual BBCE modelling.

Outline

Media Report


BBC
Sign in | Home | News | Sport | Reel | Worklife | Travel

NEWS

Home | Prince Philip | Coronavirus | Video | World | Asia | UK | Business | Tech | Science | Stories

Business | Market Data | New Economy | New Tech Economy | Companies | Entrepreneurship | Technology of Business

Economy | Global Car Industry

Welcome to BBC News, America's most trusted news source.

Study says bitcoin could derail China's climate change targets

5 days ago

Climate change

BBC Report


NFTs Are Selling for Millions. Are They Warming the Planet, Too?

Making the digital artworks requires colossal amounts of computing power, and that means greenhouse gases.

By Hiroko Tabuchi

When Chris Precht, an Austrian architect and artist, first learned about nonfungible tokens, the digital collectibles taking the art world by storm, he was so enthralled, he said, he "felt like a little kid again."

The New York Times Report


CNN BUSINESS | Markets | Tech | Media | Success | Perspectives | Videos

MARKETS			
DOW	33,607.26	-142.02	-0.42%
S&P 500	4,134.47	+6.43	+0.16%
NASDAQ	13,935.37	+86.01	+0.62%

FEATURED
Track the Covid economy
See how drastically everyday life in America has changed since the start of the pandemic

LATEST
$50 billion in rent relief is up for grabs. These landlords are working with
Apple will launch new products on April 20
Boeing's 2021 was starting off pretty well — until its latest 737 Max woes

Bitcoin mining in China could soon generate as much carbon emissions as some European countries, study finds

By Alexis Benveniste, CNN Business
Updated 1227 GMT (2027 HKT) April 9, 2021

TOP STORIES

Schneider Electric

CNN Report


Forbes

ADVERTISEMENT

Apr 6, 2021, 11:19am EDT | 2,307 views

Bitcoin Could Churn Out 130 Million Tons Of Carbon, Undermining Climate Action. Here's One Way To Tackle That

David Vetter Senior Contributor
Sustainability
Climate research, renewables and circularity

Forbes Report

Media Report

The Economist | Menu | Weekly edition | Search

Finance & economics
Apr 10th 2021 edition ›

The dirty truth

Totting up bitcoin's environmental costs

Without regulation, mining in China could consume as much energy as Italy by 2024

The Economist Report

TECHNOLOGY | NEWS | VIDEO | THE DISRUPTORS | ARTIFICIAL I

TECHNOLOGY | News Wire | Company News | Investing

Apr 6, 2021

Bitcoin mining operations in China threaten climate goals

Bloomberg News, Bloomberg News

Bloomberg Report

yahoo!finance

Search for news, symbols or companies

Sign in

Finance | News | Market Data | Videos | Industry News | Work & Management | More

UK markets clos

IKKEI 225	HANG SENG	CRUDE OIL	GOLD FUTURES	DOW
,751.61	28,497.25	60.28	1,745.10	33,585.72
12.88 (+0.72%)	+43.97 (+0.15%)	+0.58 (+0.97%)	+12.40 (+0.72%)	-159.68 (-0.47%)

TECH HUB: Goldman Sachs to create hundreds of jobs with new office in Birmingham
This is the latest example of a firm looking outside of London for talent and cheaper real estate

AFP | AFP

China's bitcoin mining rush risks derailing climate goals

Yahoo Report

CRYPTOCURRENCIES

Ripple, CoinShares, ConsenSys Join Crypto Climate Accord

CONTRIBUTOR
Jamie Crawley — CoinDesk

PUBLISHED
APR 8, 2021 10:00AM EDT

Nasdaq Report

Media Report

News Podcasts Video Technology Space NewScientist Shop Courses Events

NEWSLETTERS Sign up to read our regular email newsletters

Bitcoin mining emissions in China will hit 130 million tonnes by 2024

TECHNOLOGY 6 April 2021

By Donna Lu

New Scientist Report

nature asia

Research highlights Subject gateways Nature Index Services About

nature conferences Sustainable Solutions for Pollution Cont
April 28-29, 2021

Home / Research highlights / Environmental science: Climate impacts of Bitcoin mining in China

RESEARCH PRESS RELEASE

Like 3 Tweet

Environmental science: Climate impacts of Bitcoin mining in China

Nature Report

CCTV 央视网 .com 经济

专访清华大学教授：密集的比特币挖矿或将破坏中国的减排努力

资讯 来源：澎湃新闻 2021年04月09日 09:30 A- A+ 我要分享

原标题：专访清华大学教授：密集的比特币挖矿或将破坏中国的减排努力

中央电视台报道

美刊认为：中国须严格监管比特币“挖矿”

新华社 2021/04/08 14:14

核心提示：报道指出，在没有任何政策干预的情况下，中国的比特币挖矿活动预计将在2024年达到顶峰，耗费296.59万亿瓦时的电力。这种消费和由此产生的排放可能会破坏中国让本国能源体系碳减排的努力。

新华社报道

Outline

Insights For FinTech

- In recent years, blockchain technology has been introduced and adopted by abundant traditional industries that seek to optimize their operation process in the real world, such as supply chain finance, smart contract, international business and trade, as well as manufacturing operations.
- Although PoW is designed to decentralized Bitcoin transactions and prevent inflation, we find that it would become an energy and carbon-intensive protocol, which eventually leads to the high carbon emission patterns of Bitcoin blockchain operation in China. The evidence of Bitcoin blockchain operations suggests that with the broaden usages and applications of blockchain technology, new protocols should be designed and scheduled in an environmentally-friendly manner.

Insights For FinTech

- This change is necessary to ensure the sustainability of the network - after all, no one wants to witness a disruptive and promising technique to become a carbon-intensive technology that hinders the carbon emission reduction efforts around the world.
- The auditable and decentralized transaction properties of blockchain provide a novel solution for trust mechanism construction, which can be beneficial and innovative for a variety of industrial development and remote transactions.
- However, the high GHG emission behavior of Bitcoin blockchain may pose a barrier to the worldwide effort on GHG emission management in the near future. As a result, the above tradeoff is worthy of future exploration and investigation.
- Ultimately, the choice of adopting and using this technology lies in the hands of humans. Consequently, we should carefully evaluate the trade-offs before applying this promising technology to a variety of industries.

Thanks!