Estimating Environmental Damages Cost of Cryptocurrency Mining using Statistical Methods

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Abstract

Mining cryptocurrency uses significant amounts of power involving heavy calculations for transactions verification. In fact, an analysis by researchers at Cambridge University suggests that Bitcoin uses more electricity annually than the whole of Argentina. In this work, we build upon previous calculations of energy used for mining cryptocurrencies to estimate the per coin/dollar economic damages of air pollution emissions associated to climate impacts in the USA for mining ten prominent cryptocurrencies (Bitcoin, Bitcoin Cash, Bitcoin SV, Ethereum, Ethereum Classic, Litecoin, Dash, Zcash, Dogecoin, and Monero). Our results show that the environmental cost of mining can sometimes be as high or even higher than the amount of currency mined.

With each cryptocurrency, the rising electricity requirements to produce a single coin can lead to an almost inevitable set of negative net social benefits, without any price increase to the miners. In this paper, we give a detailed analysis of the health and climate change *cryptodamages* of mining ten different cryptocurrencies, compared to the value of the coin value created. We close with discussion of policy implications.

Key-words : Cryptocurrencies, Energy use, Air Pollution, Environmental Cryptodamage,

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1 INTRODUCTION

Cryptocurrencies are digital currencies in which transactions are verified and recorded by cryptographic algorithms managed in a decentralized system. The advent of such currencies has revolutionized the financial world and stock market. The decentralization of this new type of currency compared to the common currency known as fiat currency offers broader perspective in commercial transactions. The proof-of-work (POW) is the algorithm used in a Blockchain network to confirm transactions and produce new blocks. The majority of cryptocurrencies owners as of today are captivated by the principle of proof of work (mining) as the process of mining provide the anti-DoS attacks defense and low impact of stake on mining possibilities [26]. Miners are trying to solve a complex hash problem, i.e. to come up with a 64-digit hexadecimal number (a *hash*) that is less than or equal to the target hash, and the probability that a participant will be the one to discover the solution is related to the portion of the total mining power on the network. The POW time-stamping scheme is done by multiple miners who are competing to reach the solution the fastest. This competition contributes to the total energy required to produce a new block, which in turn produces new coins. Successful mining requires a lot of computing power [27]. Therefore, for cryptocurrency applications using blockchain, dominated by the POW process, the probability of successful mining is increased by the amount of computing work expended. Thus, the mining process generates financial value with high security, but it consumes electricity in doing so. As the supply of new coins slows, the competition of miners escalates, thus requiring ever increasing amounts of electricity.

It is well documented that the POW process produces electricity-intense resource use [5, 10, 11]. The work carried out by miners on block-chains requires a significant amount of energy since mining machines usually use powerful graphic processing unit (GPU) and/or application-specific integrated circuits (ASIC) to handle calculations, and these require high-wattage power supplies.

Energy production from burning fossil fuels releases a variety of pollutants such as carbon dioxide (CO_2), fine particulate matter (PM2.5), nitrogen oxides (NO_x), sulfur dioxide (SO_2), mercury (Hg), cadmium (Cd), and much more [2, 18, 19, 20]. These pollutants are at the origin of a more extensive and rapid deterioration of the environmental sustainability. As the energy cost for crypto-mining rises, so does the amount of carbon added to the atmosphere. Using IP-addresses to locate machines which are mining, Stoll et al. estimated substantially larger CO_2 emissions associated with Bitcoin alone, in excess of 20 million tons per year [13]. According to [21], BofA Securities, Inc. recently reported that the rise of Bitcoin has led to an astronomical surge in CO_2 emissions, an increase of over 40 million tons over the past two years. The high-energy consuming Blockchain technology causes negative—and expanding—environmental and health costs that are not borne by the cryptocurrency miners [12]. Some papers have proposed methods to evaluate the quantity of pollutants produced from mining crytocurrencies [?]. In order to assess the effectiveness of such work, it is important to be able to evaluate the monetary value of their environmental damages and health damages.

In this research, we extend the calculations in the papers by Rause and Tolaymat [1] and Goodkind et al. [2]. In particular, we investigate the environmental impacts caused by the carbon dioxide from mining ten cryptocurrencies, showing the results in the three years since their work was completed. Our work allows for the exploration of how much energy efficiency is necessary in order to positively impact the environmental damages from mining cryptocurrencies, as well as what sort of costs the society is receiving due to the work of the miners. The paper is organized as follow: In Section 2, we give a literature review. In Section 3, we describe the methodology. In Section 4, we present some preliminary results.

2 LITERATURE REVIEW

The largest source of carbon emission comes from human activities [6], such as fuel combustion, construction operations and other industrial operations. Thus, many researchers have been significantly focused on studying and quantifying the carbon emissions with their impact on the environment and human health [2, 1] and, investigating methods to reduce them. Carbon emission has caused several environmental issues, such as global warming, extreme weather events that lead to health and climate damages. Increasing concentration of greenhouse gas emissions is considered as a prime cause for these issues [31]. Carbon emission research expands over several research areas which include environmental sciences, engineering, economics, energy and more [30]. Previous literature has estimated that the large energy consumption of the Bitcoin blockchain has created considerable carbon emissions [3, 4]. It is estimated that between the period of January 1st, 2016 and June 30th, 2018, up to 13 million metric tons of CO2 emissions can be attributed to the Bitcoin blockchain [1].

Carbon emission research was initiated in 1981 with the first publication focusing on volatile organic carbon emissions of cooling tower water [35]. Thereafter several researchers explored the domain without significant impacts until the Kyoto protocol was signed in 1997. Carbon emission research became a trending topic after 2007, resulting in a significant increase in research publications. The Kyoto Protocol specified six main greenhouse gases which considerably impact the environment: namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6). Among these gases, carbon dioxide is generally considered as the most prominent contributor to global climate damages [34]. With the rising global temperatures, climate change has become a major global concern which is also considered as the most serious issue global community has to address in the 21st century [33]. Research on global carbon emissions has significantly increased after discovering carbon emissions as the major cause of climate change. Increasing carbon emissions have caused significant concern amongst the countries such as China, United States, Russia, India, European Union, and Japan as the leading carbon emitters of the world [32].

The significant carbon footprint of cryptocurrency has been well studied [7]. It was revealed by Business News [28] that a study found that just Bitcoin use alone is causing huge CO_2 emissions, over 22 megatons of carbon dioxide, which is comparable to a total emissions of cities such as Las Vegas and Vienna. Early this year (February 18, 2021) on Washington Post, Daniel Getter, director of applied Environment Social Governance research at Arabesque S-Ray, an ESG data firm admitted that data from the University of Cambridge suggests that the emissions produced by bitcoin mining are the equivalent of up to 127 million megatons of carbon dioxide, placing Bitcoin as the sixth highest-emitting company in the world, according to the company's emissions database [29].

The methodology we used to calculate power required for cryptocurrencies network and the daily social cost of carbon dioxide inspired by Krause and Tolaymat in [1, 2], are presented in the Methodology. In [1], the authors quantified the energy and carbon emissions for mining cryptocurrencies and, they estimated the per coin economic damages of air pollution emissions and associated human mortality and climate impacts of mining four cryptocurrencies (Bitcoin, Ethereum, Litecoin, and Monero) for the 2.5-year period (January 1, 2016 to June 30, 2018). They found that the four prominent cryptocurrencies were responsible for 3 – 15 million tonnes (t) of CO2 emissions and that mining these four cryptocurrencies tends to consume more energy than traditional mineral mining such as copper, gold, platinum metals, and rare earth metals (with the exception of aluminum, which has high electricity consumption) in producing an equivalent market value. Goodkind, Jones and Berrens in their paper [2] used the available exposure-response function and available estimates of social costs of carbon to monetize the negative environmental externalities of air pollution and human health damages associated with mining the same four coins over the same period 2016 – 2018 as in [1]. They found that these four coins accounted for 57.2 percent of the $369 billion in total market capitalization for 1658 listed cryptocurrencies as of March 15, 2018, with BTC alone accounted for 37.8%.

In this work, we extend the study of their economic damages of air pollution emissions from mining ten cryptocurrencies for the 5.5-year period (January 1, 2016 to June 30, 2021). We estimated the monetary damages in US dollar of the daily air pollution for producing one coin of the same cryptocurrency, with a prediction for future daily social cost per dollar and per coin from mining for the next few months. In comparing the two sets of ten data figures, the curve trends of the 'per dollar' and 'per coin' are drastically different. Thus, we are left asking which of the trends gives a more meaningful understanding of the current and future data.

3 METHODOLOGY

3.1 Data Collection

Here we use the publicly available data and mining hardware characteristics to deter- mine the power requirements for ten cryptocurrency networks. We obtain dioxide carbon emission data from [18, 19]. We collected hashrate data of ten common cryptocurrencies from BitInfoCharts [25]. This is a public website that hosts cryptocurrency information with a wide range of attributes, including daily price, daily hashrate, average transaction fee, etc. We utilize web scraping with Python packages such as BeautifulSoupand Requeststo collect hashrate, transaction fee, profitability and other attributes required for the computations. We first apply filters to select the attributes of interest, which will update the web page URL. Then, we collect the web page content through Requests and parse the content using BeautifulSoup. Finally, we select the correct portion of the web content and place it into a data frame for further processing. This approach is selected because BitInfoCharts hosts open-source up-to-date data. Even though the web pages only display the graphics (trend lines of the prices, for example), the actual data is available on the back end to power the graphics, which is what enabled our data collection.

3.2 Methodology

Our values for power requirement are calculated using the four different categories of power efficiency estimates from January 1st of 2016 to June 30th 2021 for ten cryptocurrencies. The currency data features were selected from Bitinfocharts.com [25]. We obtained data on emission rates per KWh of electricity generation for the USA for carbon dioxide. In order to quantify environmental damages due to cryptocurrency mining, we use an econometric formula developed by previous research papers [1, 2] to compute historical environmental damages. We then leverage time series forecasting models to predict future daily social cost per dollar and per coin given historical trends. The forecasting models used is FBProphet. Prophet is an open source software developed by Facebook to generate forecasts for time series data [36]. It applies additive models to accommodate for non-linear trends with different seasonality.

To compute the electricity required for producing one coin each day, we needed to find the power efficiency (PE) data of machines used by the miners for the Proof of Work (POW) mining process. We were able to find that information at [22, 23]. It is important to mention that before the arrival of specialized machines with application-specific integrated circuit rigs (ASIC), it was possible for miners to practice proof-of-work using conventional computers to which they could have just added a graphic processing unit (GPU) to enhance their computers. Therefore, for some of the cryptocurrencies studied in this project the power efficiency is collected from both GPU and ASIC rigs. Moreover, for better accuracy of the results, we performed the computation using the four following categories: best machines (those with the lowest PE), median machines (cumulative median of PE from machines as they appear into the market), average machines (cumulative average of PE from machines as they appear into the market), and finally the worst case (assuming that the highest PE from all machines during this period of study remain used by miners). Additionally, as machines appear into market at different dates during the year, we decided to define the four categories described above three times per year: from January to April, May to August and from September to December.

We first present the definitions for the terms used in the computations.

1. *Power Required*

$$PR(MW) = HR\left(\frac{h}{s}\right) * \left(\frac{1}{10^9}\right)\left(\frac{Gh}{h}\right) * PE\left(\frac{J}{Gh}\right) * \left(\frac{1}{10^6}\right), \tag{1}$$

PR is the power required for a cryptocurrency mining network (megawatt), HR is the average network hashrate (number of hashes per second), and PE is the power efficiency of the GPU or ASIC rigs used by the miners in (Joules per Giga hash).

2. *Number of blocks added to the chain per day*

$$NB(block) = \frac{24 * 60(min)}{Time(\frac{min}{block})}, \tag{2}$$

NB is the number of blocks added to the chain per day, and Time is the average time in minute necessary to complete one block.

3. *Number of coins rewarded per day*

$$NC(coin) = NB(block) * CB\left(\frac{coin}{block}\right), \tag{3}$$

CB is the number of coins rewarded per block completed. By multiplying CB with NB, we can derive NC, the number of coins rewarded to the miners per day.

4. *Daily energy consumed by coin mined (MWh/coin)*

$$EC\left(\frac{MWh}{coin}\right) = \frac{PR(MW) * 24}{NC(coin)}, \tag{4}$$

With NC and PR from previous calculations, we can compute EC, the energy consumed by coin mined per day.

5. *Carbon dioxide emitted per coin mined (Kg CO2/coin)*

$$CO2e\left(\frac{Kg}{coin}\right) = EC\left(\frac{MWh}{coin}\right) * CO2\,Emissions\,rate\left(\frac{Kg}{MWh}\right), \tag{5}$$

CO2e is the carbon dioxide emitted per coin mined, and the CO2 emissions rate is obtained from the 2020_camd_emissions data for the total of CO2 emitted each year and the total electricity end use in the United States from 1995 to 2020.

6. *Daily metric tons of CO_2 emitted (t CO2)*

$$DMT\_CO2e(t) = CO2e\left(\frac{Kg}{coin}\right) * \frac{1}{10^6} * NC(coin), \tag{6}$$

From CO2e and NC, we can derive DMT_CO2e(t), which represents the daily metric tons of CO_2 emitted.

7. *Daily social cost of carbon per coin mined (USD/coin)*

$$DSCC\left(\frac{USD}{coin}\right) = DMT\_CO2e(t) * 51\left(\frac{USD}{t}\right) * \frac{1}{NC(coin)}, \tag{7}$$

where DSCC is the daily social cost of carbon in US dollars per coin mined, DMT_CO2e(t) is known, and NC is known.

8. *Daily social cost of carbon per dollar mining (USD)*

$$DSCCD = DSCC\left(\frac{USD}{coin}\right) * \frac{1}{Market\ price\left(\frac{USD}{coin}\right)}, \tag{8}$$

where DSCCD is the daily social cost of carbon per dollar mining, DSCC is known, and the market price is obtain from the data.

4 PRELIMINARY RESULTS

From the formulas described in the previous section, we calculated the daily climate impacts and associated monetary damages in US dollar for producing one dollar from mining each of the ten cryptocurrencies (**BTC** = Bitcoin, **BCH** = Bitcoin cash, **BSV** = Bitcoin SV, **DSH** = Dash coin, **DOGE** = Doge coin, **ETH** = Ethereum, **ETC** = Ethereum classic, **LTC** = Litecoin, **XMR** = Monero, and **ZEC** = Zcash) in the USA. Those values were used to estimate the monetary damages value for daily social cost of carbon dioxide emissions from mining these cryptocurrencies (Figures 1-10 and 11-12). In each case, the gray dots correspond to the data, and the solid colored curves correspond to the fit of the data that was acquired using the methods described in the previous section. In cases where there is no available data for a portion of the time period, such as for example when currency did not exist for the whole period, the data is preceded by a gray line at height zero. We also calculated the monetary damages in US dollar of the daily air pollution for producing one coin of the same ten cryptocurrencies. These values are used to perform estimation of the monetary damages in US dollar for producing one coin (Figures 1-10). Again here, the gray dots and curves represent the data and fits respectively. Both set of estimates are made on data starting from the beginning of 2016 and ending on June 30, 2021. In addition to showing our calculated damages for times in the past, the graphs presented show prediction for future daily social cost per dollar and per coin from mining for the next few months.

In comparing the two sets of ten data figures, note that since the value of the currency with respect to the dollar is constantly fluctuating, the transformation between the two sets of graphs is a nonlinear transformation. In particular, we fitted the data separately in the two different settings. Therefore the curves in the set of two median comparison figures is not the same fit as the set of ten figures. Since these curve trends are drastically different, we are left asking which of the trends gives a more meaningful understanding of the current and future data.

As shown in Figures 11-12, the monetary damages in US dollar for producing one dollar from mining started low and reached a peak. With the exception of Monero and Zcash, the predictions show a decrease toward a negative value. Since there will always be a positive value for damages, any negative value is clearly an artifact based on the fact that our predictions are bound to be inaccurate if we look too far in the future, especially since the energy usage underwent a lot of flux due to quarantine precautions. Certainly in order to compare two different cryptocurrencies, we need to convert them into a common currency, and the US dollar is a standard choice. However, this has the downside of the effect of carbon cost being hidden behind a potentially inflated value of one or more of the cryptocurrencies. That is, the decrease seen in these two comparison figures, could be more of a sign that the cryptocurrencies have had a rapid increase in value in comparison to traditional currencies, such as the US dollar. Therefore, while this is a good way to compare relative social costs of two different cryptocurrencies, it also runs the risk of being a bad way to assess the actual damage of the mining process.

In the set of ten figures, rather than considering the carbon cost per dollar, we consider the carbon cost per coin mined. As mentioned above, since we are fitting two different data sets which are related to each other by a non-linear transformation, the curve trends of the ten graphs shown in Figures 11-12 do not necessarily correlate with their respective graphs (Figures 1-10) of the monetary damages in US dollar for producing one coin from mining. For example, with the exception for Bitcoin Cash and Bitcoin SV, the predicted daily monetary damages in US dollar for producing one coin show an increased value leading up to the current time and into the future. While this set of ten figures and data fits has the downside that different currencies cannot be compared to each other, we believe that it is a more accurate reflection of the social cost of each cryptocurrency as a function of time. In particular, this indicates that the social cost of mining most of the currencies is not only getting worse, but in the case of Bitcoin and Ethereum for example, the rate at which it is growing is increasing.

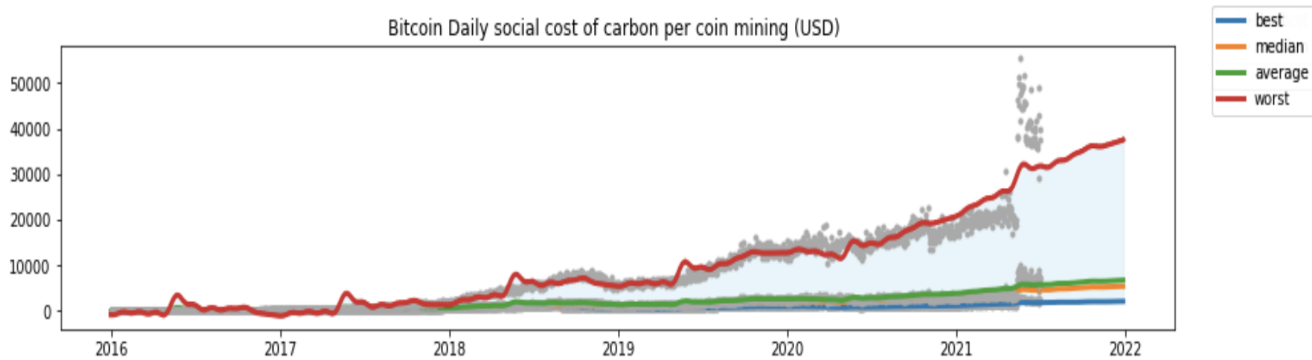


Figure 1: Bitcoin shows steady increase in daily social cost of carbon per coin mined from 2016 to 2021, and the trend is expected to continue in 2022 up to $40,000/coin.

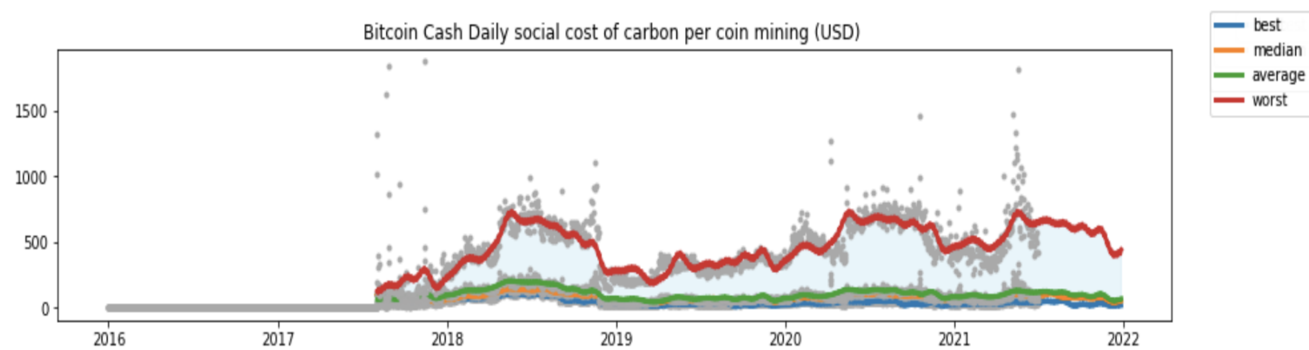


Figure 2: Bitcoin Cash has relatively flat trend line with some variations around about $750/coin.

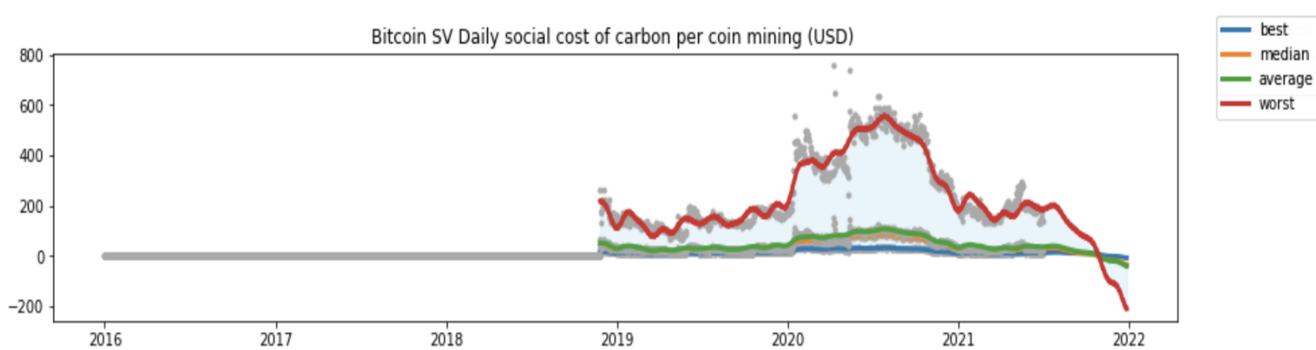


Figure 3: Bitcoin SV shows peak daily social cost of carbon around June of 2020 and has seen a decreasing trend since then. We acknowledge that the forecast is not always accurate as it cannot go below zero.

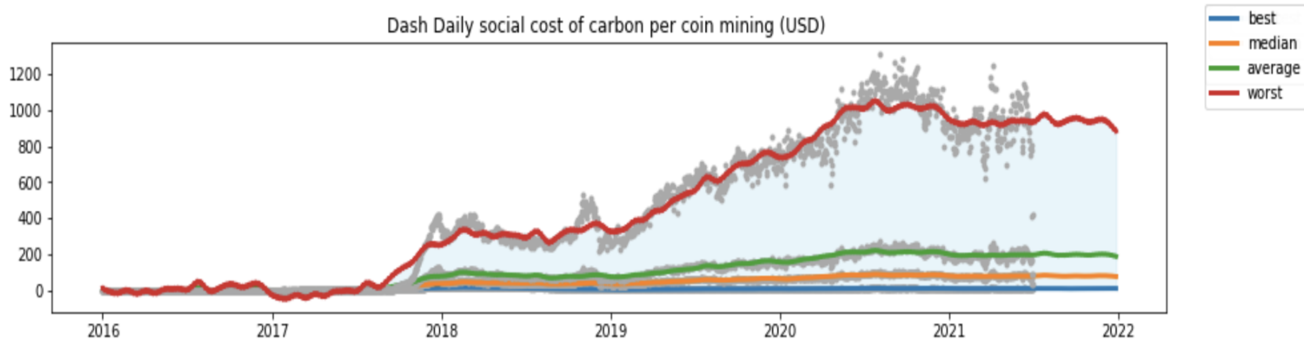


Figure 4: Dash: Similar to Bitcoin, we also observe increasing daily social cost of carbon for Dash starting form 2018. The cost has remained steady and high starting from June 2020 and is expected to remain so into 2022.

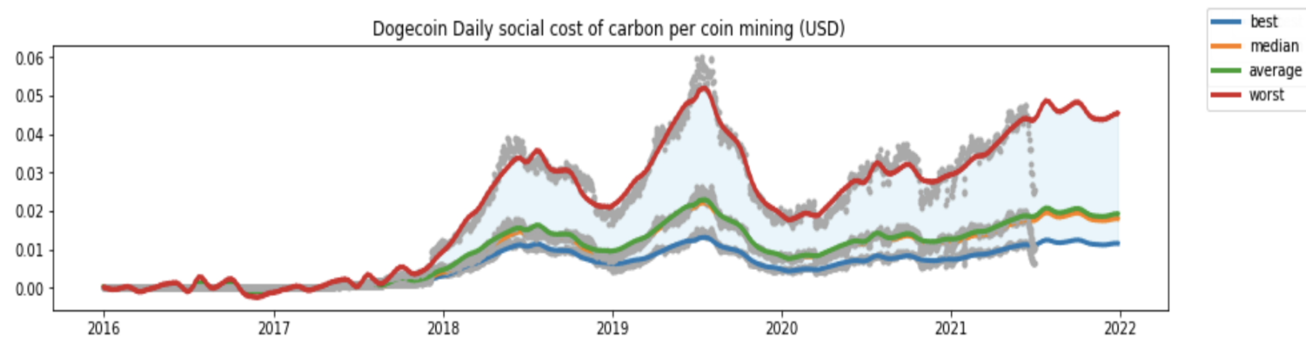


Figure 5: Dogecoin has shown ups and downs in daily social cost of carbon per coin since 2016. There are two peaks in mid 2018 and 2019. It goes down at the beginning of 2020 but has shown steady increase ever since. It is expected to go up slowly into 2022. Although note that the scale for Dogecoin daily social cost of carbon per coin has remained below \$0.07/coin.

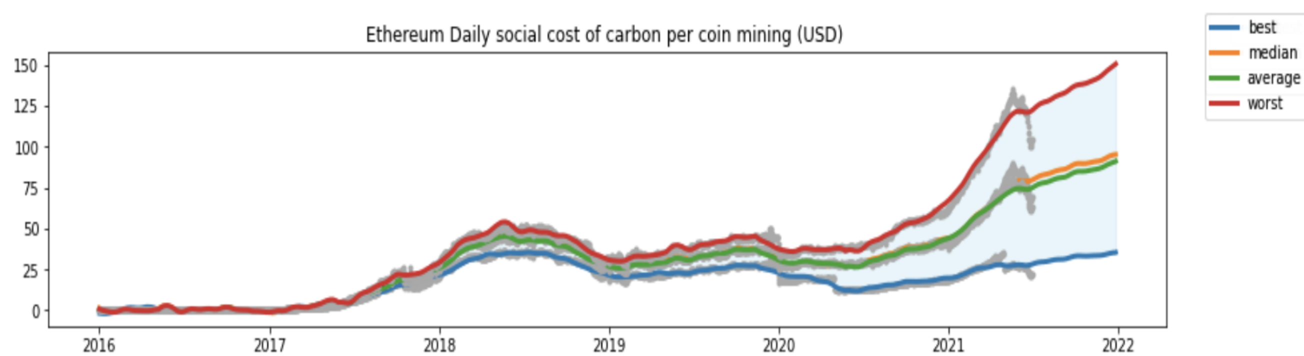


Figure 6: Ethereum follows a similar trend as Ethereal classic. There is a small bump in mid 2018 and steady increase from the beginning of 2020. The worst case is expected to go up to \$150/coin by 2022.

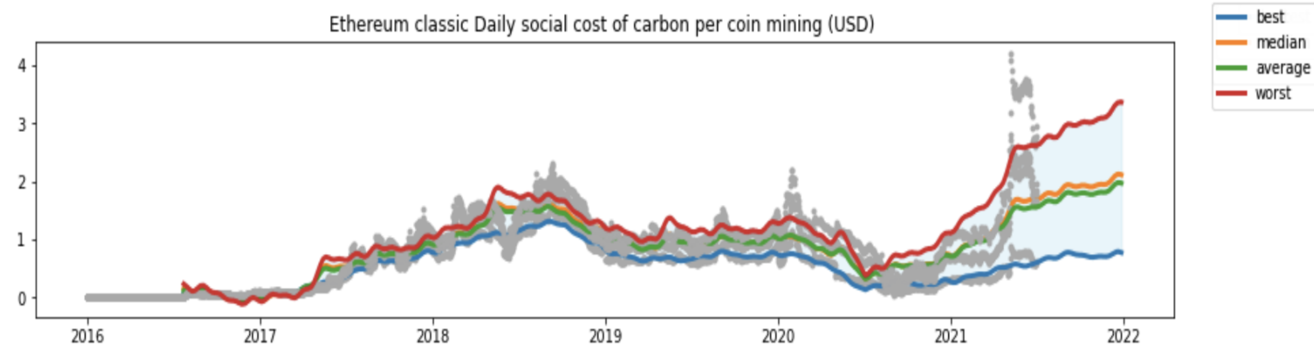


Figure 7: Ethereum classic has a small peak in late 2018 ($2/coin), goes down to its lowest since 2017 around 2020, and goes up again in 2020 and 2021. The worst case is expected to rise up to $3.5/coin by 2022.

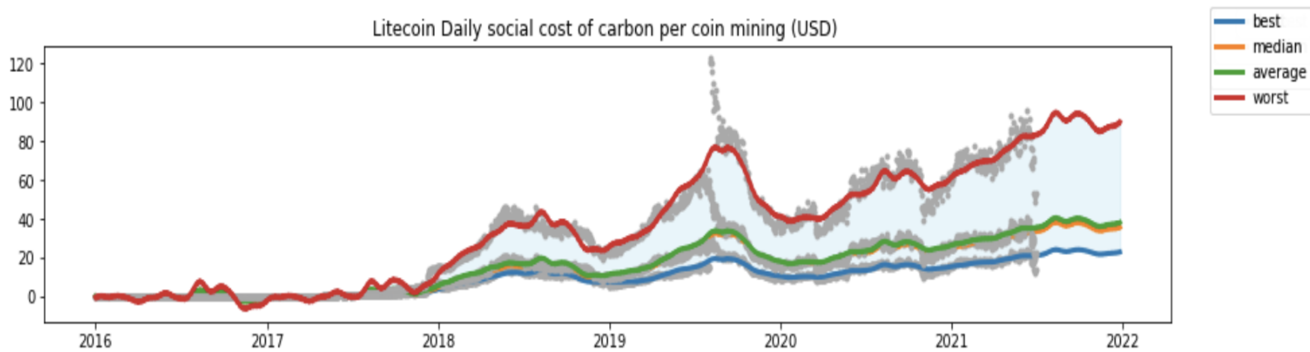


Figure 8: Litecoin experiences bumps in mid 2018 and mid 2019. Simlar to Ethereum and Ethereum classic, Litecoin goes up in 2020 and 2021, although at a slow speed. The worst case is expected to get to $100/coin by 2022.

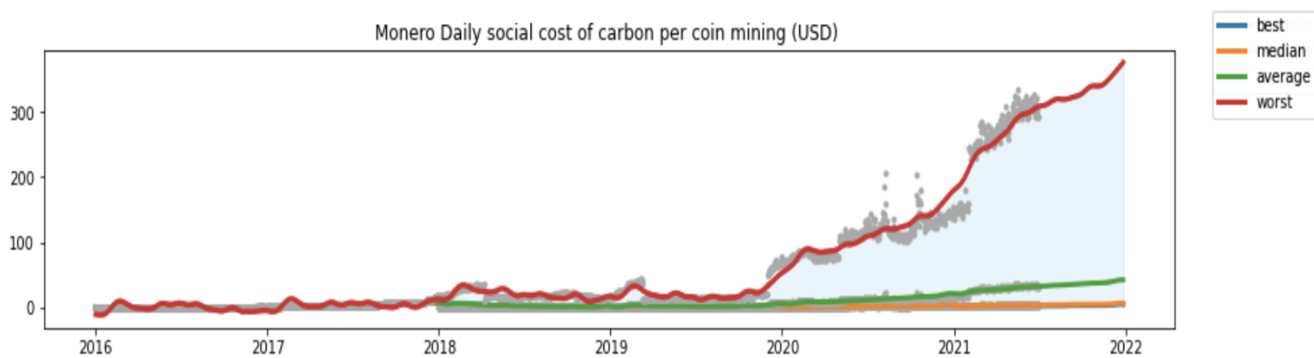


Figure 9: Monero has low carbon social cost from 2016 to 2020. It goes up at a steady speed from 2020 till Jun 2021, and the worst case is expected to get to $300/coin by 2022, but the best case is expected to remain at a very low price.

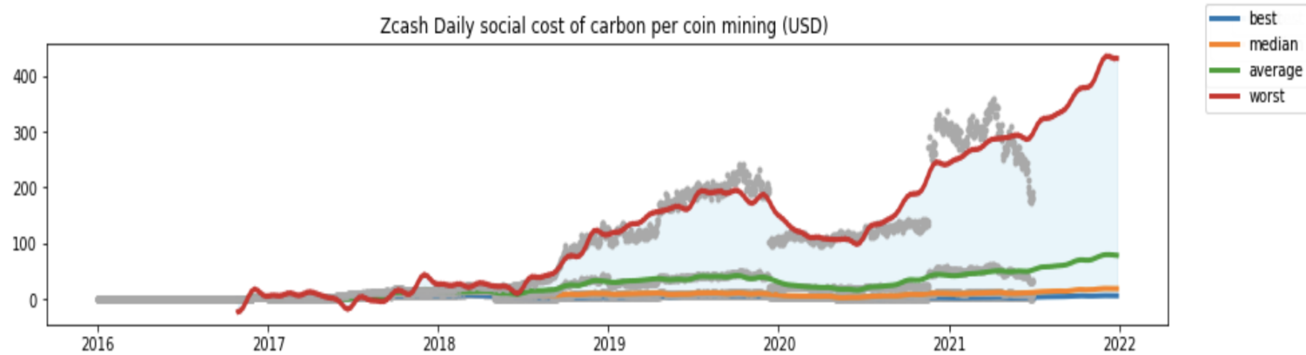


Figure 10: Zcash generally shows a steady increase form late 2017 until 2020 with a small dip in 2019. The worst case is expected to go up to $400/coin although the best case is expected to remain at a low percentage.

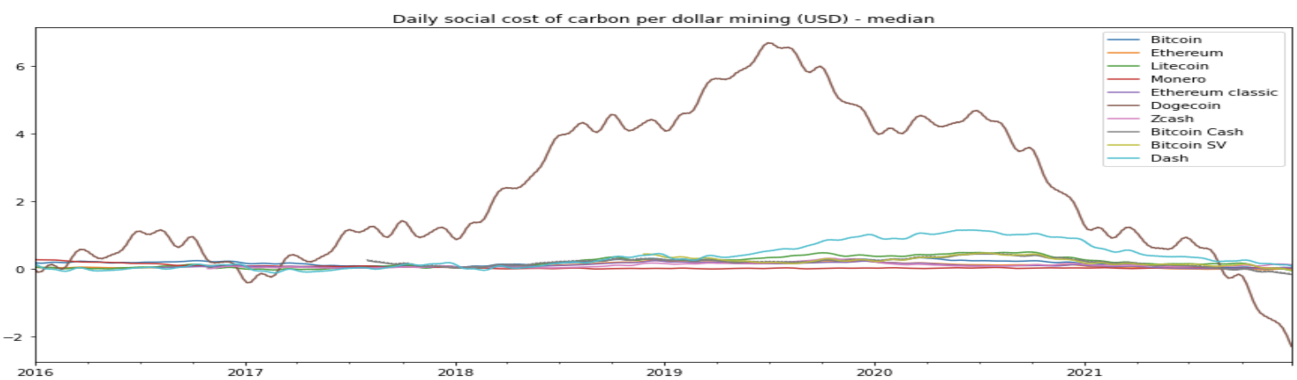


Figure 11: Daily social cost of carbon per dollar (USD) Comparison - median

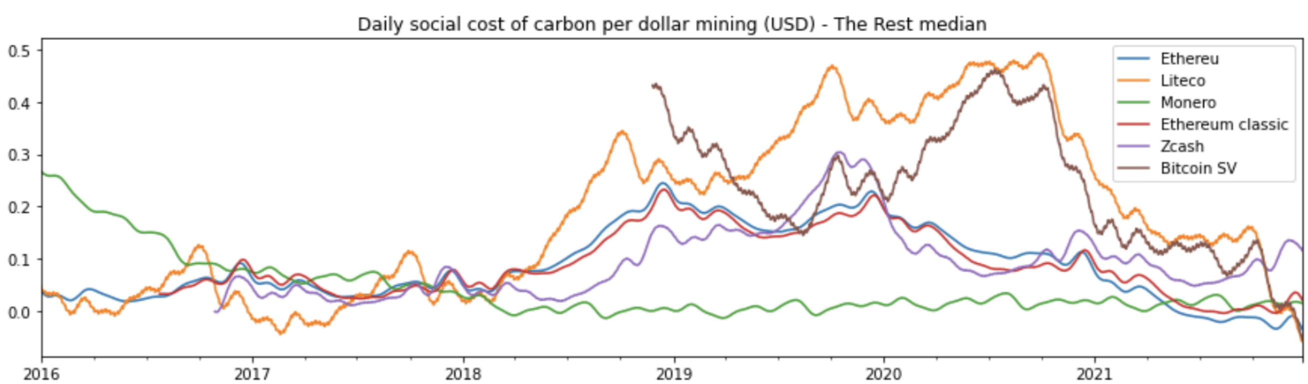
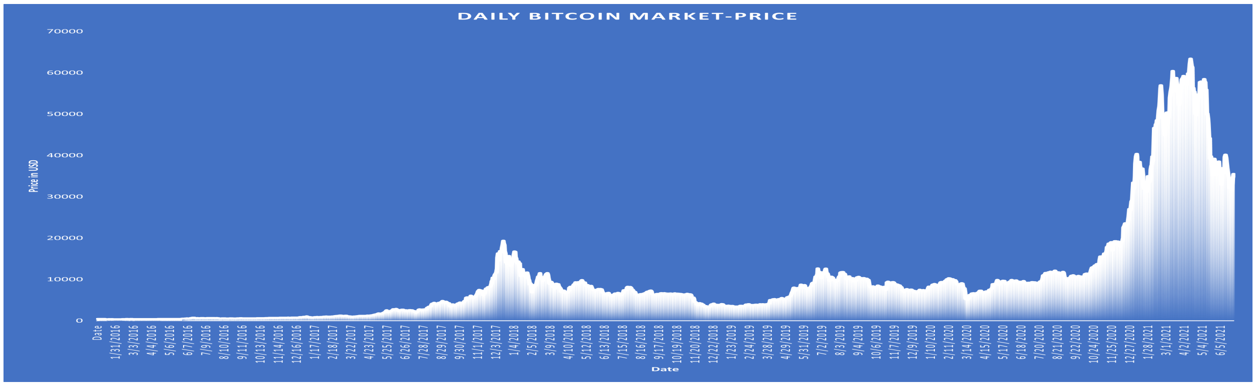


Figure 12: Daily social cost of carbon per dollar (USD) Comparison - median



We further evaluate the yearly average environmental damages for all four categories of PE see Tables 1-12 in the appendix.

5 CONCLUSION

The focus of this research has been to investigate and analyse various scenarios of the social damages that the carbon dioxide emitted during mining ten cryptocurrenices in the USA. Our result indicates that in 2021, each \$1 of Bitcoin value created was responsible for \$0.04 for the best PE, \$0.09 for the median PE, \$0.10 for the average and \$33 for the worst PE in climate damages in the US while each \$1 of Dash value created was responsible of \$0.04 for the best PE, \$0.41 for the median PE, \$1.04 for the average and \$5.02 for the worst PE. The first impression of our comparison graphs appears as if there are other cryptocurrencies that cause more mining damages on the environment than Bitcoin. From one set of graphs, perhaps one thing looks worse, but also we recognize that the price being inflated could mask the actual cost of mining. It might just mean that Bitcoin is more highly valued than other currencies rather than that the social cost is in any real way less than the other currencies. Perhaps after the prices level off after a period of hype (not a technical term), then the actual social cost will be more clear. Furthermore, the social cost of Bitcoin on a per coin basis is growing rapidly with what appears as a positive second derivative - so that is an indicator that the social cost in the future may become dangerously high. In our future work, we plan to estimate the growth rate to compare to our current results.

6 APPENDIX

Table 1: Climate damages in USD per coin mined (Best Values)

	2016	**2017**	**2018**	**2019**	**2020**	**2021**
BTC	45.65	178.40	710.91	707.41	983.85	1525.45
BCH	-	66.64	73.89	23.31	36.66	31.29
BSV	-	-	15.86	10.51	26.29	10.42
DSH	0.05	2.09	9.75	5.04	8.38	7.88
DOGE	9.46E-05	7.70E-04	0.0083	0.0089	0.0066	0.0095
ETH	0.32	7.66	30.96	24.09	16.36	25.95
ETC	0.06	0.39	1.08	0.69	0.39	0.47
LTC	0.10	0.88	9.86	12.98	13.14	18.70
XMR	0.34	4.05	0.18	0.20	0.99	2.36
ZEC	1.70	3.54	4.23	5.54	2.37	3.24

Table 2: Climate damages in USD per coin mined (Median Values)

	2016	**2017**	**2018**	**2019**	**2020**	**2021**
BTC	100.20	223.36	1090.48	1570.38	2401.22	3864.03
BCH	-	76.38	104.14	51.02	86.07	71.99
BSV	-	-	32.29	21.58	56.16	22.95
DSH	0.05	6.78	38.55	49.87	79.35	74.62
DOGE	9.46E-05	9.42E-04	0.0110	0.0147	0.0109	0.0149
ETH	0.36	9.47	39.22	32.39	32.51	64.09
ETC	0.06	0.48	1.36	0.92	0.70	1.24
LTC	0.10	1.09	13.04	21.58	21.84	29.42
XMR	0.34	4.05	0.27	0.30	1.49	3.54
ZEC	1.70	6.41	9.96	10.15	5.62	11.40

Table 3: Climate damages in USD per coin mined (Average Values)

	2016	2017	2018	2019	2020	2021
BTC	82.02	267.11	1253.59	1690.64	2631.36	4251.83
BCH	-	79.88	114.91	52.84	93.19	82.57
BSV	-	-	34.54	22.91	63.77	26.23
DSH	0.05	15.01	81.90	117.78	200.22	188.28
DOGE	9.46E-05	1.17E-03	0.0119	0.0153	0.0114	0.0159
ETH	0.36	9.33	38.08	32.07	31.90	62.68
ETC	0.06	0.47	1.32	0.92	0.69	1.19
LTC	0.10	1.34	14.13	22.40	22.68	31.25
XMR	0.34	4.05	2.62	2.38	11.92	28.31
ZEC	1.70	6.41	18.21	36.51	24.92	49.50

Table 4: Climate damages in USD per coin mined (Worst Values)

	2016	2017	2018	2019	2020	2021
BTC	100.20	502.11	2876.04	4895.65	8386.54	14135.54
BCH	-	108.09	259.83	151.53	295.12	272.30
BSV	-	-	90.47	68.32	210.98	90.66
DSH	0.05	49.91	317.64	552.72	963.18	905.77
DOGE	9.46E-05	2.14E-03	0.0258	0.0348	0.0259	0.0373
ETH	0.41	10.77	43.71	38.64	44.02	100.01
ETC	0.07	0.55	1.52	1.10	0.93	1.92
LTC	0.10	2.48	30.56	50.98	51.60	73.46
XMR	0.34	4.05	19.73	21.69	108.67	258.05
ZEC	1.70	9.28	47.37	167.34	139.96	285.47

Table 5: Climate damages in USD per dollar produced (Best Values)

	2016	2017	2018	2019	2020	2021
BTC	0.08	0.06	0.10	0.10	0.10	0.04
BCH	-	0.17	0.11	0.10	0.14	0.05
BSV	-	-	0.17	0.11	0.14	0.05
DSH	0.01	0.01	0.04	0.06	0.11	0.04
DOGE	0.41	0.61	2.37	3.40	2.43	0.22
ETH	0.03	0.04	0.10	0.14	0.07	0.01
ETC	0.05	0.04	0.09	0.13	0.06	0.02
LTC	0.03	0.02	0.14	0.20	0.25	0.10
XMR	0.15	0.06	0.001	0.003	0.01	0.01
ZEC	0.03	0.02	0.02	0.11	0.05	0.02

Table 6: Climate damages in USD per dollar produced (Median Values)

	2016	2017	2018	2019	2020	2021
BTC	0.17	0.08	0.17	0.23	0.24	0.09
BCH	-	0.20	0.17	0.22	0.33	0.11
BSV	-	-	0.17	0.11	0.14	0.05
DSH	0.01	0.01	0.17	0.59	1.02	0.41
DOGE	0.41	0.70	3.13	5.65	4.03	0.35
ETH	0.04	0.05	0.12	0.19	0.12	0.03
ETC	0.05	0.05	0.11	0.18	0.11	0.05
LTC	0.03	0.03	0.18	0.33	0.42	0.16
XMR	0.15	0.06	0.002	0.01	0.02	0.01
ZEC	0.03	0.04	0.06	0.20	0.10	0.09

Table 7: Climate damages in USD per dollar produced (Average Values)

	2016	2017	2018	2019	2020	2021
BTC	0.14	0.10	0.19	0.25	0.26	0.10
BCH	-	0.20	0.18	0.22	0.36	0.13
BSV	-	-	0.37	0.24	0.34	0.13
DSH	0.01	0.03	0.37	1.41	2.57	1.04
DOGE	0.41	0.82	3.38	5.87	4.19	0.37
ETH	0.04	0.05	0.12	0.19	0.12	0.03
ETC	0.05	0.05	0.11	0.17	0.11	0.05
LTC	0.03	0.03	0.20	0.34	0.43	0.17
XMR	0.15	0.06	0.02	0.04	0.15	0.12
ZEC	0.03	0.04	0.15	0.74	0.45	0.37

Table 8: Climate damages in USD per dollar produced (Worst Values)

	2016	2017	2018	2019	2020	2021
BTC	0.17	0.18	0.45	0.71	0.83	0.33
BCH	-	0.28	0.43	0.64	1.14	0.43
BSV	-	-	0.97	0.70	1.13	0.44
DSH	0.01	0.09	1.49	6.67	12.34	5.02
DOGE	0.41	1.35	7.33	13.36	9.53	0.87
ETH	0.04	0.05	0.14	0.23	0.16	0.05
ETC	0.06	0.05	0.12	0.21	0.14	0.08
LTC	0.03	0.04	0.42	0.78	0.99	0.39
XMR	0.15	0.06	0.15	0.38	1.36	1.09
ZEC	0.03	0.05	0.42	3.38	2.52	2.14

Table 9: Climate damages in coin per coin mined (Best Values)

	2016	2017	2018	2019	2020	2021
BTC	0.08	0.06	0.10	0.10	0.10	0.04
BCH	-	0.17	0.11	0.10	0.14	0.05
BSV	-	-	0.17	0.11	0.14	0.05
DSH	0.01	0.01	0.04	0.06	0.11	0.04
DOGE	0.41	0.61	2.37	3.40	2.43	0.22
ETH	0.03	0.04	0.10	0.14	0.07	0.01
ETC	0.05	0.04	0.09	0.13	0.06	0.02
LTC	0.03	0.02	0.14	0.20	0.25	0.10
XMR	0.15	0.06	0.001	0.003	0.01	0.01
ZEC	0.03	0.02	0.02	0.11	0.05	0.02

Table 10: Climate damages in coin per coin mined (Median Values)

	2016	2017	2018	2019	2020	2021
BTC	0.17	0.08	0.17	0.23	0.24	0.09
BCH	-	0.20	0.17	0.22	0.33	0.11
BSV	-	-	0.35	0.22	0.30	0.11
DSH	0.01	0.01	0.17	0.59	1.02	0.41
DOGE	0.41	0.70	3.13	5.65	4.03	0.35
ETH	0.04	0.05	0.12	0.19	0.12	0.03
ETC	0.05	0.05	0.11	0.18	0.11	0.05
LTC	0.03	0.03	0.18	0.33	0.42	0.16
XMR	0.15	0.06	0.002	0.01	0.02	0.01
ZEC	0.03	0.04	0.06	0.20	0.10	0.09

Table 11: Climate damages in coin per coin mined (Average Values)

	2016	2017	2018	2019	2020	2021
BTC	0.14	0.10	0.19	0.25	0.26	0.10
BCH	-	0.20	0.18	0.22	0.36	0.13
BSV	-	-	0.37	0.24	0.34	0.13
DSH	0.01	0.03	0.37	1.41	2.57	1.04
DOGE	0.41	0.82	3.38	5.87	4.19	0.37
ETH	0.04	0.05	0.12	0.19	0.12	0.03
ETC	0.05	0.05	0.11	0.17	0.11	0.05
LTC	0.03	0.03	0.20	0.34	0.43	0.17
XMR	0.15	0.06	0.02	0.04	0.15	0.12
ZEC	0.03	0.04	0.15	0.74	0.45	0.37

Table 12: Climate damages in coin per coin mined (Worst Values)

	2016	2017	2018	2019	2020	2021
BTC	0.17	0.18	0.45	0.71	0.83	0.33
BCH	-	0.28	0.43	0.64	1.14	0.43
BSV	-	-	0.97	0.70	1.13	0.44
DSH	0.01	0.09	1.49	6.67	12.34	5.02
DOGE	0.41	1.35	7.33	13.36	9.53	0.87
ETH	0.04	0.05	0.14	0.23	0.16	0.05
ETC	0.06	0.05	0.12	0.21	0.14	0.08
LTC	0.03	0.04	0.42	0.78	0.99	0.39
XMR	0.15	0.06	0.15	0.38	1.36	1.09
ZEC	0.03	0.05	0.42	3.38	2.52	2.14

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