An Order-of-Magnitude Estimate of the Relative Sustainability of the Bitcoin Network

A critical assessment of the Bitcoin mining industry, gold production industry, the legacy banking system, and the production of physical currency

WORKING PAPER

Hass McCook
BE (Hons I) MEngSc (Distinction) MBA (Oxon)

3rd Edition – February 11 2015

Data as at End of Difficulty Cycle
ending Block 342,719 c. 26/1/2015 –
Hashrate: 295,442,739 GH/s
Difficulty: 41,272,873,895

@HassMcCook

au.linkedin.com/in/hassmccook/

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Executive Summary

There has been a lot of uncertainty surrounding the sustainability of the Bitcoin network, with this fascinating nascent technology facing several unsubstantiated claims by uninformed individuals that Bitcoin is highly unsustainable from a social, economic and environmental point of view. This paper aims to disprove or support these claims about the sustainability of the Bitcoin network, and provide an order-of-magnitude comparison of the relative sustainability of Bitcoin when compared with the incumbent banking industry, the gold production industry, and the process of printing and minting of physical currency.

Widely available public information strongly refutes claims that Bitcoin is unsustainable, and shows that the social, environmental and economic impacts are a minuscule fraction of the impacts that the legacy wealth and monetary systems have on our society and environment.

The results of the research are summarised in the tables below.

Comparison of Annual Economic Costs

	Gross Yearly Cost
Gold Mining	USD$105 billion
Gold Recycling	USD$40 billion
Paper Currency & Minting	USD$28 billion
Banking System Electricity Use	USD$63.8 billion
Banking System (All Expenses)	USD$1870 billion
Bitcoin Mining	USD$0.375 billion

Comparison of Annual Environmental Costs

	Energy Used (GJ)	Tonnes CO_2 Produced
Gold Mining	475 million	54 million
Gold Recycling	25 million	4 million
Paper Currency & Minting	39.6 million	6.7 million
Banking System	2340 million	390 million
Bitcoin Mining	3.97 million	0.66 million

Comparison of Annual Socioeconomic Costs

	Gold	Fiat Currency	Bitcoin
Worker Deaths	Over 50,000 historically recorded & Over 100 per year	0	0
Corruption	USD$600m	USD$1.60 trillion	Black Swan Events Only
Money Laundering		USD$2.65 trillion	
Black Markets		USD$1.80 trillion	
Institutional Fraud / Theft	USD$21 billion across two single events & several billion historically recorded	USD$3800 billion/year & several trillion historically recorded	< USD$0.5 billion ever recorded
Transactional Fraud	N/A – all historical use of counterfeit gold	$190 billion	$0
Inflation	Deflationary (Long-term)	3.9% per year (*time to loss of 50% loss of value: 17.5 years*)	Deflationary (Long-term)

Preface to the Third Edition

This third edition serves to shore up the section on Bitcoin economics with clarifications around base assumptions, as well as updating overall cost and environmental impact considering the staggering improvements to economic ($/GH) and environmental (W/GH) efficiency of bitcoin mining equipment since the last edition was published.

All hashrate data used in this 3rd edition was data as at Block 342,719, the end of the typical 2016-block difficulty cycle, which occurred on January 26, 2015. Hashrate as at the difficulty change (Difficulty 41,272,873,995)

Since publishing the second edition, rationalised average network figures have changed as follows:

- $/GH has plummeted from $2.63/GH to approximately $0.65/GH, a 75% drop
- W/GH has gone from 0.89 W/GH to approximately 0.56 W/GH, a 37% drop
- Network hash rate has increased by 54%, from 130 PH/s to 200 PH/s
- Market share of cloud hashing operations has decreased dramatically

As efficiency increases have substantially outpaced hash rate increases, cost to mine a bitcoin has gone down substantially, from roughly $600/coin, to roughly $450/coin, a 25% drop.

Limitations of Research

It should be noted that this research is an order of magnitude, so mining efficiencies and mix assumptions can differ by more than +/- 10% depending on the price of electricity and hash-power that large hardware manufacturers and private pool miners have access to, thanks to research and development and economies of scale.

Upcoming Fourth Edition

The fourth edition will contain updates on the sustainability of the Gold industry using the latest market data, an update on the contemporary bitcoin mining technology and data, and updates to fiat-based social costs such as the latest scams, ponzis, quantitative easings, and damning leaks about major international banks assisting in tax avoidance and money laundering.

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Introduction

Scope

The scope of this research is to undertake a critical assessment of the social, environmental and economic impacts of the way we currently transact and transfer wealth, be it through legacy systems like gold and fiat currencies, or through newer digital cryptographic ones.

This research also aims to give readers a much clearer idea of the human and environmental impacts associated with both current and future monetary systems, and allow them to draw their own conclusions on the relative sustainability of the old and new systems when viewed from a holistic "triple-bottom-line" approach. Although it is not necessarily fair to compare Bitcoin to the entire legacy banking system, there was doubt in the community about the impact of the legacy banking system, and thus, it has been quantified for completeness.

Methodology

This research involved a broad and deep literature review of publicly available information, and various extrapolative calculations based on this data. All references have been cited, and calculation steps demonstrated throughout this paper. All extrapolative calculations have been undertaken using two different methods so as to sense-check all results, and sensitivity analyses undertaken where there are data shortfalls.

Exclusions

- Impact assessment of producing gold mining machinery
- Impact assessment of storing and transporting gold
- Impact assessment of constructing the world's 600,000 bank branches, but not their ongoing annual emissions

Gold – Mining & Recycling

Introduction

Gold has been used for millennia as a means to project and protect wealth. In terms of projection of wealth, as can be seen from the data below, 52% of all gold ever mined is used for jewellery and palatial adornments. In terms of protection of wealth, central banks hold 18% of the world’s gold supply and other investors hold 16% (Hewitt, 2008). It also has practical applications, with 10% of yearly demand coming from industry (World Gold Council, 2012), with almost 12% of the world’s supply of gold held inside technological products, and is lost forever unless recycled – which has its own costs attached to it. For completeness, according to the World Gold Council (2012), over **2700 tonnes of gold were produced** and over **1600 tonnes of gold were recycled in 2011**.

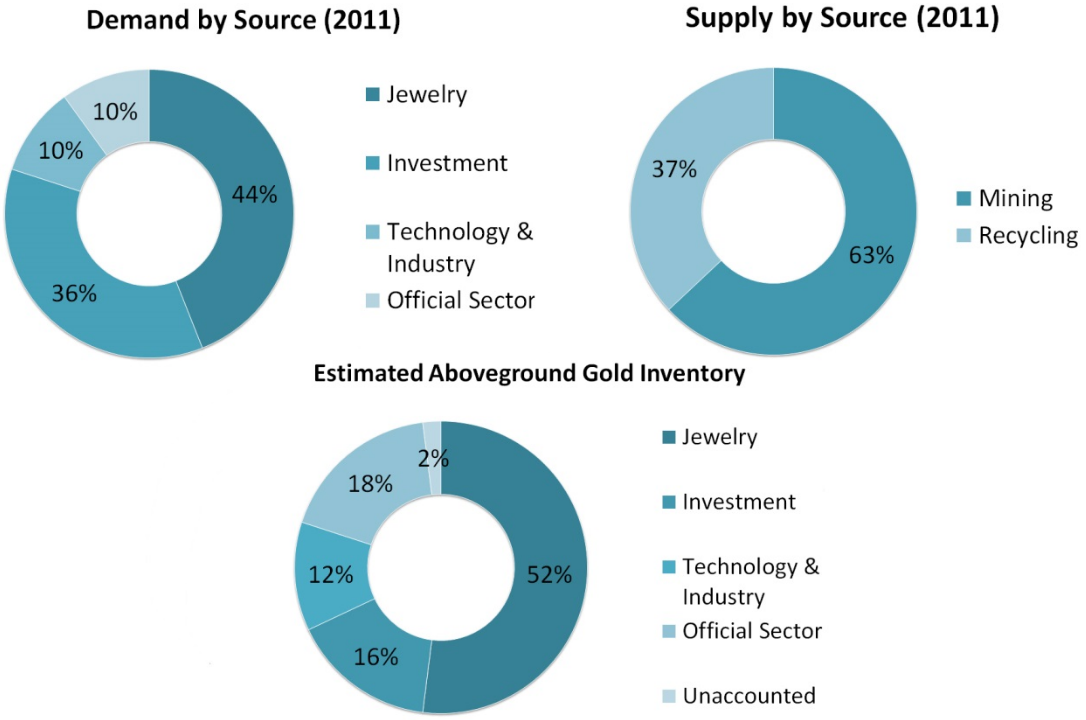
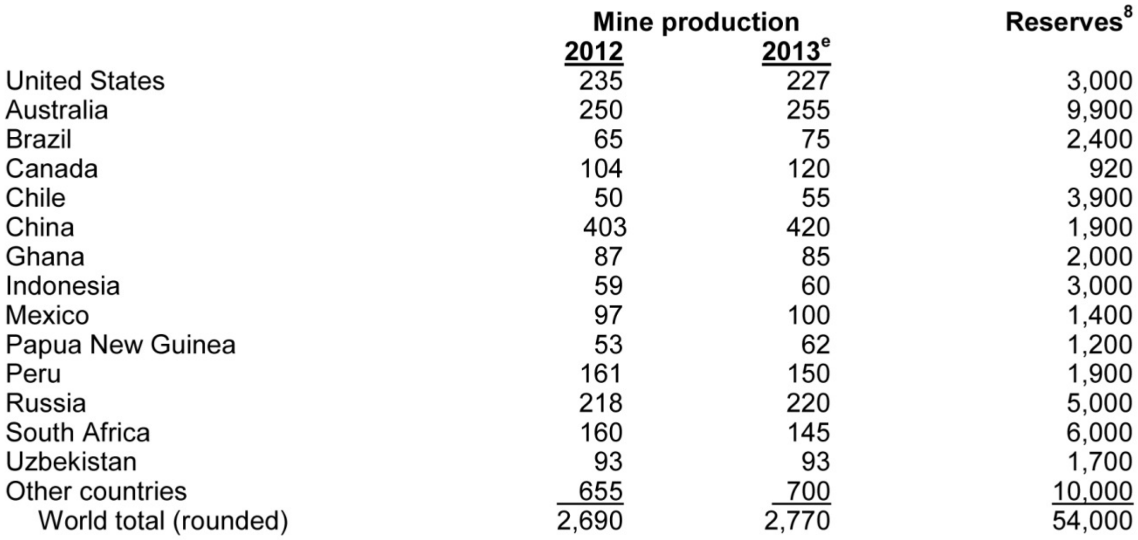


Figure 1 - Gold - Key Statistics (Sources: World Gold Council (2012), GFMS (2011), Hewitt (2008))

The reason gold is valuable is due to its inherent properties. It is highly durable, malleable and never loses its lustre. Most importantly, it is scarce, and becomes increasingly more difficult and expensive to mine – so it is safe from inflation. It is for these reasons, as well as its applications for industry, that make gold demanded, and hence, valuable. But because of its weight, and the need to rely on special instruments to detect counterfeit gold, it became useless as a prolific day-to-day currency. The following sections discuss the lifecycle of mining, as well as the triple-bottom-line; the economic, environmental and social costs of gold mining.

Future Trends

Gold is becoming harder to mine and scarcer, which means costs, impacts and resource use of mining will continue to increase at an increasing rate. Relative labour costs are also increasing dramatically, which could be a large driver in future mining cost. As most of the energy used in mining comes from less clean sources like diesel fuel and non-renewables, there isn't much hope for reducing the footprint of gold mining in the future. With that said, there is hope for improvement in gold recycling as national grids transition to green energy, and statistics on annual mining fatalities are improving. As can be seen from the below figure, at current production rates, known global gold reserves will be depleted in 20 years' time, and new production will rely on recycling.



	Mine production		Reserves[8]
	2012	2013[e]	
United States	235	227	3,000
Australia	250	255	9,900
Brazil	65	75	2,400
Canada	104	120	920
Chile	50	55	3,900
China	403	420	1,900
Ghana	87	85	2,000
Indonesia	59	60	3,000
Mexico	97	100	1,400
Papua New Guinea	53	62	1,200
Peru	161	150	1,900
Russia	218	220	5,000
South Africa	160	145	6,000
Uzbekistan	93	93	1,700
Other countries	655	700	10,000
World total (rounded)	2,690	2,770	54,000

Figure 2 - World Gold Production & Reserves (U.S. Geological Survey, 2014)

Mining Lifecycle

As can be seen from the graphic below (Minerals Council of Australia, 2014) the mining of gold is quite an involved process, and the lifecycle of a mine is typically quite long and varied (upwards of 20 years). Although there are triple-bottom-line costs associated with each of these stages, the costliest stages are the fourth, fifth and sixth stages – construction, production and rehabilitation.

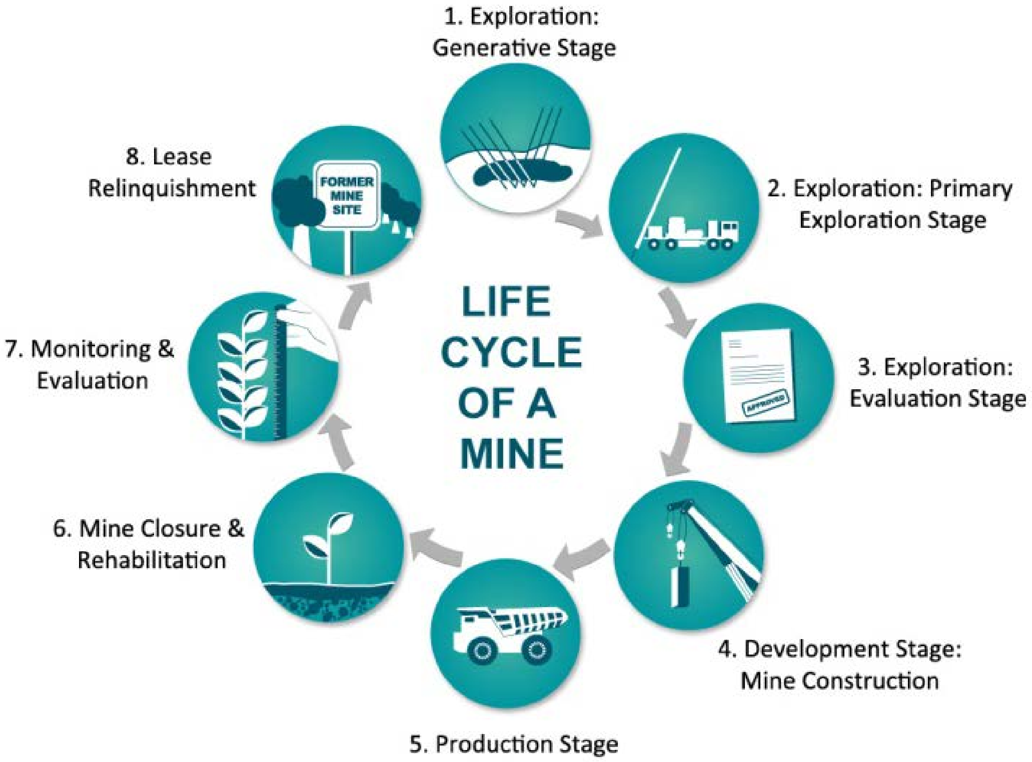


Figure 3 - The Gold Mining Lifecycle (Minerals Council of Australia, 2014)

Mine construction provides the necessary infrastructure to allow for a productive mine; this includes bulk earthworks, construction of roads and facilities, and can generally take several years to complete. Rehabilitation involves returning the land to as close to its pre-mining condition as possible, in order to allow plant and animal life to flourish, or the original owner of the land to use it as they please. Although these activities have huge costs and impacts associated with them, they pale in comparison to mining production.

Figure 4 shows the process of extracting gold from the ground. Whilst this paper will not discuss the activities in the process chain, you will notice that large volumes of rock, water, and cyanide are used in the process of producing gold. There is a plethora of peer-reviewed scientific literature and industry-based data on the economic, environmental and social impacts of these processes, and they will be discussed in the following sections of this report.

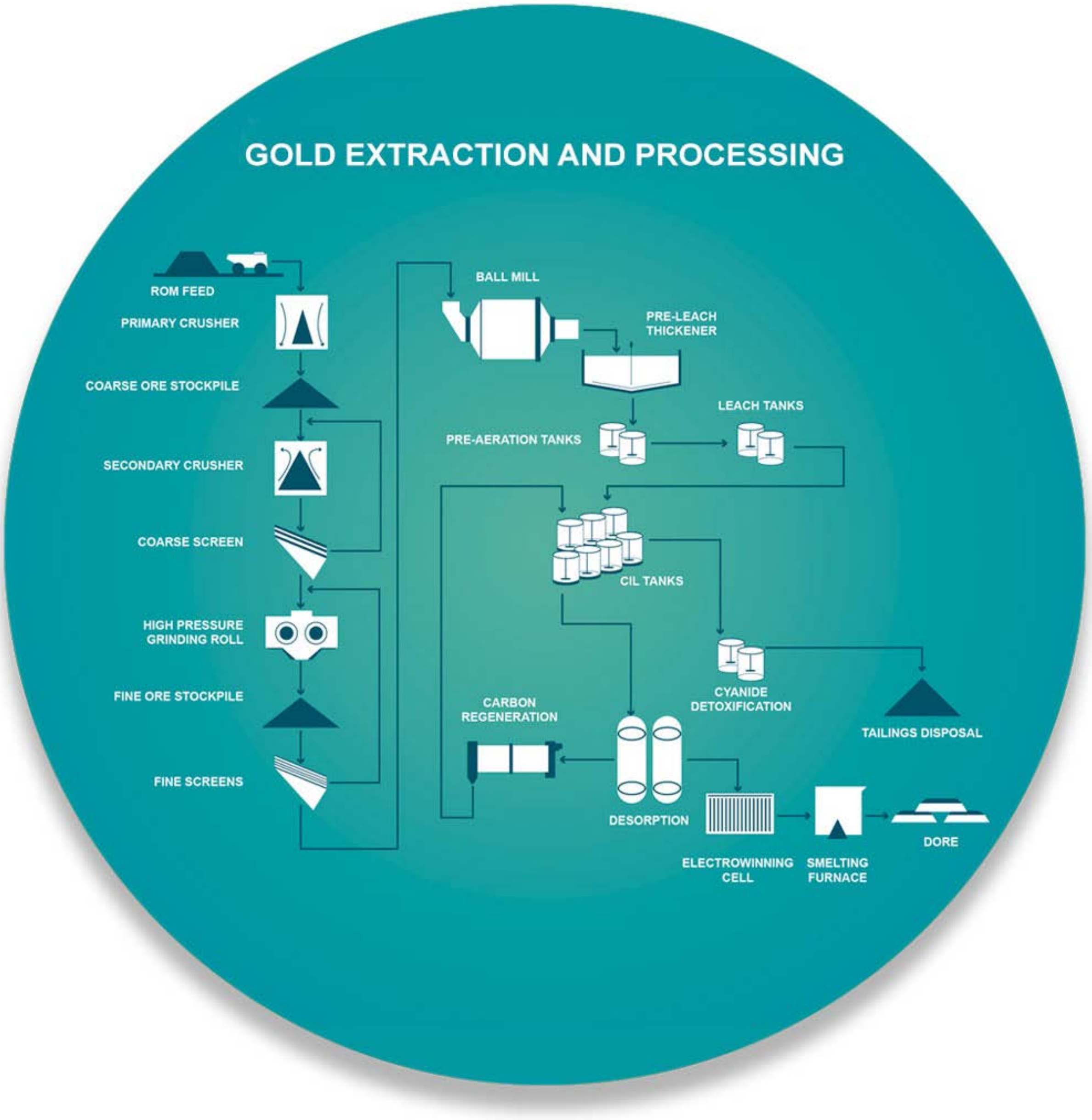


Figure 4 - Mining Production Process (Minerals Council of Australia, 2014)

Economic Costs of Mining

At the time of writing, price of gold was approximately USD$1250/ounce. This section of the report will provide industry data on the economic cost to miners to produce an ounce of gold.

In early February 2014, the World Gold Council noted that the average industry cost of production is **USD$1200/ounce**, with 30% of the industry becoming unprofitable if the gold price drops below that level (Rudarakanchana, 2014).

Barclay's commodities research provides similar figures, their report from April 2013 shows that the marginal cost of production was **USD$1104/ounce** (Barclays Commodities Research, 2013).

Andrew Su, CEO at brokerage firm Compass Global Markets concurred, stating that cost of producing gold in Australia had jumped to over **USD$1000/ounce** in 2013 (Naidu-Ghelani, 2013).

2,700 tonnes, or just over 96 million ounces, of gold were mined in 2012. At an average of **$1100/ounce**, this puts the economic cost of mining gold at **USD$105.6 billion**.

Environmental Costs of Mining

When the cost of mining is easily and conveniently packaged into a cover-all USD$1100/ounce figure, the devastating toll mining has on the environment can be easily overlooked. The below table compares and contrasts various lifecycle analyses of gold-mining, presented in different peer-reviewed journals and scientific sources:

	Energy Consumption (GJ/kg Au)	Water Consumption (kL/kg Au)	Greenhouse Emissions (t CO_2 / kg Au)	Cyanide Consumption (kg / kg Au)	Waste Rock Generated (t / kg Au)
(Mudd, 2007) & (Mudd, 2013)	146	477	11.5	150	1800
(Norgate & Haque, 2012)[1]	200	260	18	*N/A*	1270
(Norgate & Haque, 2012)[2]	300	260	27	*N/A*	1270
(Oxfam, 2004)	*N/A*	*N/A*	*N/A*	*N/A*	2821
Low Average	***175***	***300***	***20***	***150***	***1500***

Table 1 - Environmental Costs of Gold Mining

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[1] Data for non-refractory ore

[2] Data for refractory ore

With 2,700 tonnes, or, 2.7 million kilograms of gold mined each year, using low average numbers from the above literature review, total yearly impacts can be summarised as follows:

	Energy Consumption (Gigajoules)	Water Consumption (Litres)	Greenhouse Emissions (Tonnes CO_2)	Cyanide Consumption (Tonnes)	Waste Rock Generated (Tonnes)
Yearly Burden	475 million	810 billion	54 million	400 thousand	4 billion

Table 2 - Gold Mining Environmental Impacts - Summary

Recycling

Gold can be recycled, and frequently is - Figure 1 showing that just over a third of all gold produced each year is recycled. Recycling is significantly less energy intensive than mining gold, however, definitive data does not exist as to the exact energy savings (US EPA, 2012). As an indication of how much energy is saved recycling, here are statistics for other metals and products (The Economist, 2007):

- Aluminium – 95% saved
- Steel – 60%
- Plastics – 70%
- Glass – 5-30%
- Paper – 40%

Assuming optimistic energy savings of 90%, energy used to recycle gold would be **475 million GJ** x **0.5** *(ratio of recycled to mined gold)* x **(1 – 90%)** *(energy saving)* = **approx. 25 million GJ.**

Converting GJ of energy to tonnes of CO_2 & Dollar Cost

The most consistent approach to converting GJ of energy to tCO_2 would be to use a weighted average of tCO_2 produced by the source of primary energy supply. This is calculated in the table below (Moomaw, et al., 2011), (Sovacool, 2008), (US Department of Energy, 2013):

Primary Energy Source (PES)	% World Total PES	g CO2/kWh	$ / MWh
Biofuels & Waste	10%	18	$111
Coal	27.3%	1001	$100 - $135
Oil	32.4%	778	$100
Natural Gas	21.4%	443	$67 - $130
Nuclear	5.7%	66	$108
Hydroelectric	2.3%	13	$90.3
Other (Wind, Solar, Geothermal)	0.9%	~20	$144.3 - $261.5
Weighted Average		**~600 g/ kWh**	**$100 / MWh**

Table 3 - Economic & Environmental Cost of Electricity Generation - By Source

1GJ is equivalent to 277.77 kWh or 0.2777 MWh, therefore, 25 million GJ results in **4 million tonnes of CO_2** produced at 600g/kWh. To sense-check these results, mined gold results in 54 million tonnes of CO_2. Therefore, it can be concluded that a saving of over 90% of carbon emissions if gold is recycled, if the above assumptions hold true. This conclusion seems logical, due to not having to deal with huge amounts of waste rock, water, cyanide and other chemical by-products during recycling.

At an average cost of $100 / MWh of electricity generated, the economic cost of energy used for recycling would be **USD$694.25 million**.

Assuming that all recycled gold is low-grade 14 carat, this means that cost to acquire 1600 tonnes of scrap gold is as follows:

$$\frac{14\ carat}{24\ carat} \times \frac{32150\ troy\ oz}{1\ tonne} \times \frac{USD\$1300}{troy\ oz} \times 1600\,\frac{tonnes}{year} = \boldsymbol{USD\$39\ Billion}$$

The cost to acquire recycling facilities has not been considered, as this is expected to be marginal. After rounding, we can conclude that the recycling of gold costs about **USD$40 Billion per year** (and rising), or about **$780/ounce**.

Social Costs of Gold Mining

The obvious major social costs of gold mining are native land-owner rights, human rights abuses to obtain "conflict gold", and unacceptably high worker fatality rates. According to research by Oxfam (2004), 50% of all newly mined gold is taken from native lands.

Gold is a renowned conflict mineral, with more than **USD$600m** of gold estimated to leave Congo every year alone – this gold is tainted with physical and sexual violence, and human enslavement. The mining of gold allows local warlords to continue to finance their armies, causing suffering to millions of Africans (Raise Hope for Congo, 2014).

Most striking are the statistics on worker fatalities, which whilst incomplete and incomprehensive due to difficulty in obtaining reliable international data, still paint an ominous picture.

Country	Data Period	Fatalities	Source
USA	1869 - 2010	272	(United States Mine Rescue Association, 2010)
South Africa	1911 - 1984	44214	(Wagner, 1988)
South Africa	2001 - 2011	1277	(Chamber of Mines of South Africa, 2012)
Australia	1970 – 2006	105	(Kahler, 2006)

Table 4 - Select International Gold Mining Fatality Data

As can be seen, statistics from a very small sample of gold producing countries show almost 50,000 fatalities in the last century alone. In addition to this, gold has been mined for centuries, surely causing tens of thousands of more deaths prior to statistics being recorded. Also to be noted, the above data only cover fatality statistics, and overlook injuries and long-term effects on health such as tuberculosis, silicosis and other occupational health diseases.

Gold Investment Fraud

In June 2014, China's chief auditor discovered **USD$15 billion** worth of loans backed by falsified gold transactions (News, 2014). In another single event, BRE-X, a Canadian gold mining scam, cost investors **USD$6.5 billion** in the biggest mining scandal of all time (Ro, 2012). Precious metal fraud has cost Americans USD$300 million since 2001 alone (Miedema & Bartz, 2014)), but on a global and historical scale, the damage has been significantly worse. There are several other documented and undocumented large-scale precious metal frauds that have occurred throughout history, which would be impossible to completely quantify.

Cash Printing & Coin Minting (Physical Currency)

Introduction

Money makes the world go round, and for the past several hundred years, paper currency and coins were the physical manifestation of money. Once upon a time, most paper currency in the world was backed by gold and directly exchangeable for it. This system of backing currency with tangible, universally exchangeable reserves was known as The Bretton Woods system, and was used to help the world rebuild economically after World War II (United Nations, 1948). On August 15, 1971, US President Richard Nixon ended the Bretton Woods System (Ghizoni, 1971), in what is now known as "The Nixon Shock", allowing all currencies to float freely, with only the backing of the faith and credit of their issuing sovereign state. This type of currency is known as "fiat currency", i.e., currency that is given value by government decree (Keynes, et al., 1978). This report will not discuss the relative merits and drawbacks of gold-backed currency and fiat-money, only the triple-bottom-line impacts of each.

Future Trends

With the built-in "infinite" inflation of fiat money, more and more physical currency will need to be printed and minted every year, unless we move to a completely digital system of transaction.

According to a research report issued by Smithers-Pira (2014) on the world security printing market, "*digitisation and convergence are two megatrends that the security printing industry needs to come to terms with. They can be seen as a threat jeopardising the very existence of the industry, or as an opportunity to innovate and evolve in order to address risk in a broader context. In the near foreseeable future, however, security printing will continue to fulfil its critical role of preventing and detecting alterations, forgeries and copies, and support product authenticity*".

In terms of printing trends, countries like Australia and Canada use polymer-based notes which reduces both economic and environmental costs of physical currency significantly, with the United Kingdom poised to go polymer in 2016 (Allen, 2013).

Coins, which have a high environmental impact due to the metal required to produce them, will most likely be phased out over the next 40 years. The reason for this is it currently costs the United States Government 1.83 cents to make a 1 cent coin, and 9.41 cents to make a 10 cent coin (Zielinski, 2014). Ireland has spent €11.8m to produce €7.1m worth of 1 Euro cent coins (Reilly, 2013). Over time, due to increasing metal costs, it will become untenable for governments to make real losses on production of currency. Some jurisdictions, like Australia, discontinued their 1 cent and 2 cent coins in 1990 (Royal Australian Mint, 2014), and as inflation continues on towards infinity, it will be less and less economically viable to produce such low denominations of currency, and therefore we might expect impacts due to minted coins to reduce over time.

Banknotes

According to the US Federal Reserve, the life-span of non-polymer paper money varies based on denomination, as shown below.

Denomination	Estimated Life Span
$1	5.9 years
$5	4.9 years
$10	4.2 years
$20	7.7 years
$50	3.7 years
$100	15.0 years

Table 5 - Estimated Lifespans of U.S. paper money (U.S. Federal Reserve, 2014)

A report prepared for The Bank of Canada ahead of the implementation of Polymer notes found that they will typically last at least 2.5 to 4 times as long as paper notes (PE Americas; Tryskele, 2011), (Ahlers, et al., 2010).

Once notes have reached the end of their useful life, they are typically pulped, compressed into bricks, and sent to an official government incinerator where they are burned, leading to environmental impact during both creation of new notes and destruction of old ones (Jackson, 2010).

Coins

After coins are minted from a typical mix of copper and steel with nickel plating, they are put into circulation where their average life is roughly 25 years (U.S. Mint, 2014).

Once coins have reached their useful life, or are too worn and mutilated for circulation, they are returned to the mint for recycling (U.S. Mint, 2014).

Currency in Circulation

M0 & M1 Money Supply

The M0 money supply is defined as the total amount of monetary assets available in an economy at a specific time (Johnson, 2005). The M1 money supply accounts for all physical currency circulating in an economy, but global M1 figures are difficult to obtain. The below table shows global M0 figures from 2008. After the global financial crisis, world money supply increased dramatically, however, this didn't translate highly into printed physical currency, i.e. M1 supply – just more numbers on a screen in a financial institution, i.e. M0 supply. The rest of this chapter will simplify the analysis greatly by assuming similar proportions for M0 and M1 money supply, and typically only consider the Euro, USD and Yen, who account for 60% of the world total, and extrapolate figures from there.

Name of Country	M0 (US$bn)	M1 (US$bn)	M2 (US$bn)	M3 (US$bn)	Exchange (1USD =)	Date Taken
Australia	37.7	208.0	459.3	962.0	1.0426 AUD	Apr-08
Brazil	56.3	114.3	519.2	1,060.8	1.6141 BRL	May-08
Canada	49.0	386.6	800.1	1,228.6	1.0114 CAD	May-08
China	440.5	2,236.2	6,363.0	N/A	6.8552 CNY	May-08
Denmark	10.6	162.6	211.7	237.3	4.7401 DKK	Feb-08
E.U.	1,013.4	6,072.7	12,039.9	14,197.4	0.6355 EUR	May-08
India	139.9	256.6	947.9	949.1	43.200 INR	Jun-08
Indonesia	16.6	39.7	151.9	N/A	9174.3 IDR	May-07
Japan	680.1	3,641.4	6,901.6	11,367.9	107.01 JPY	Apr-08
Kuwait	2.7	19.9	80.2	80.2	0.2667 KWD	May-08
Mexico	38.1	132.0	575.0	606.4	10.310 MXN	Apr-08
Norway	8.6	144.3	281.9	N/A	5.1225 NOK	Apr-08
Poland	47.4	165.1	283.0	288.2	2.0822 PLN	May-08
Russia	153.8	N/A	570.1	N/A	23.412 RUB	Apr-08
Saudi Arabia	19.8	111.6	187.2	224.9	3.7547 SAR	May-08
Singapore	12.7	52.6	233.9	240.8	1.3607 SGD	Apr-08
South Africa	13.9	96.2	192.1	235.2	7.7208 ZAR	May-08
South Korea	56.7	300.7	1,350.1	2,163.5	1000.6 KRW	Apr-08
Sweden	16.1	222.6	N/A	315.4	6.0088 SEK	Dec-07
Switzerland	35.4	257.3	421.9	609.5	1.0298 CHF	May-08
Turkey	22.8	45.2	199.7	215.5	1.2228 TRY	Jun-08
U.A.E.	7.1	49.4	154.0	189.5	3.6742 AED	Dec-07
U.K.	99.1	1,990.7	3,291.1	3,882.3	0.5055 GBP	May-08
U.S.	832.6	1,388.3	7,688.1	13,800.0	1.0000 USD	Jun-08
Venezuela	6.2	43.7	71.9	71.9	2.1522 VEF	May-08

Figure 5 - World M0 Money Supply - 2008 (Hewitt, 2008)

Coins

The next sections will use the Euro and the USD to illustrate this point further, and attempt to extrapolate production to other markets.

US Dollar

Coin	1 ¢	5 ¢	10 ¢	25 ¢	50 ¢	$1 (Pres.)	$1 (NA)	Total
Coins Produced (millions)	62918	10482	17450	20023	90	781	1257	**113000**
Coin Weight (grams)	2.5	5	2.268	5.67	11.34	8.1	8.1	
Metal Used (tonnes)	157296	52410	39576	113532	1021	6329	10180	**380344**

Table 6 - USD Coins in Circulation (produced 1999 – 2014) (U.S. Mint, 2014) (CoinNews, 2012)

Euro

Coin	€ 0.01	€ 0.02	€ 0.05	€ 0.10	€ 0.20	€ 0.50	€ 1	€ 2	Total
Circulating Coins (millions)	27892	21770	17200	12725	9716	5374	6457	5048	**106180**
Weight per coin (g)	2.3	3.06	3.92	4.1	5.74	7.8	7.5	8.4	
Total (tonne)	64152	66616	67424	52173	55770	41917	48428	42403	**438882**

Table 7 - Euro Coins in Circulation as at February 2014 (European Central Bank, 2014)

Japan

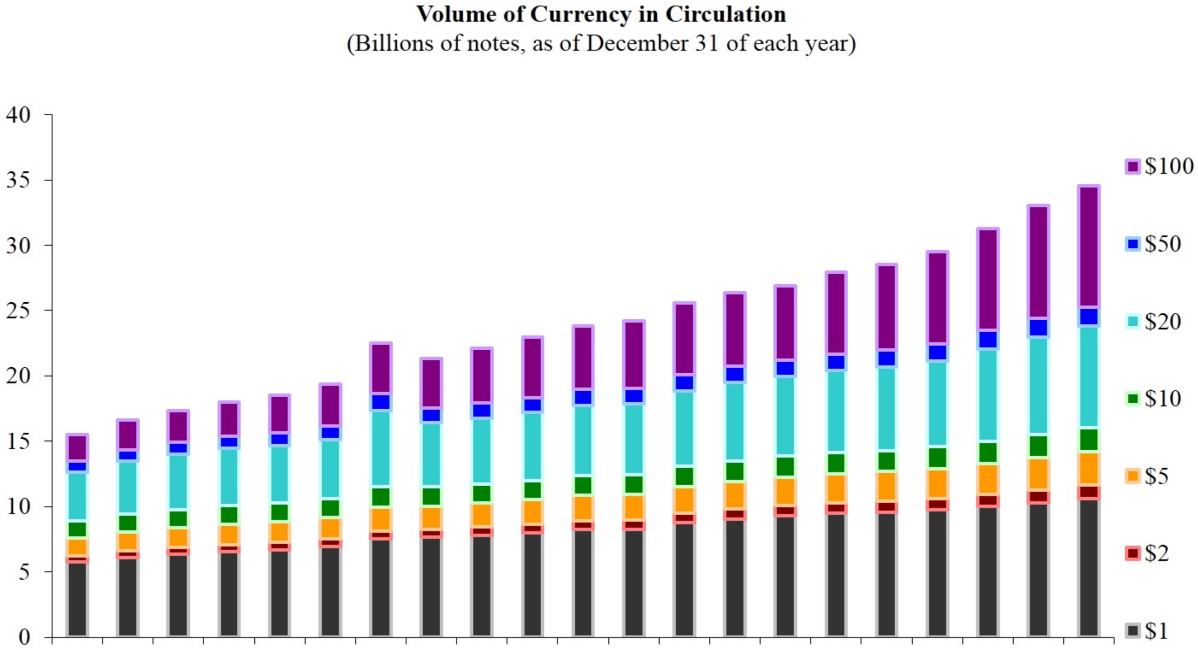
Japan bucks the trend of the US and EU and only has about 4.5 billion coins in circulation, over 20 times less than the EU or USA (Statistics Japan, 2014).

Rest of the World

Statistics from India show over 1 trillion coins in circulation – roughly 4 times the quantity of USD coins and Euro coins combined (Chinnammai, 2013). Combining the USD, EU and India accounts for only one third of the world’s population, so to be conservative, it will be assumed that 1.5 trillion coins are circulating around the planet, at an average weight of 3.5 tonnes per million coins, i.e., 5.25 million tonnes of metal circulating in the form of coins.

Banknotes

Due to their higher value, there are much less banknotes in the world than coins, as demonstrated in the US example in the figure below. According to the US Federal Reserve, there is approximately USD$1.27 trillion in circulation, of which $1.22 trillion is in over **35 billion** Federal Reserve notes.



Includes Federal Reserve notes, U.S. notes, and currency no longer issued.

Excludes the volume of denominations larger than the $100 note.

Figure 6 - Volume of USD currency in circulation (U.S. Federal Reserve, 2014)

The EU has **15.8 billion notes** in circulation that are valued at €933.7 billion as at February 2014 (European Central Bank, 2014).

Japan, the country with the 3rd biggest M0 supply has **86.6 billion banknotes** in circulation (Statistics Japan, 2014).

With the US, EU and Japan accounting for 60% of the world’s M0 money supply, and through assumption, 60% of the world’s M1 money supply, it can be assumed that at least 200 billion bank notes are in circulation around the world.

Banknotes

Smithers-Pira estimates the global market for security printing in 2018 to reach **USD$35.3 billion**, based on a compound annual growth rate of 5.9% between 2013 – 2018, putting the current global market size at **USD$26.5 billion** (Smithers Pira, 2013).

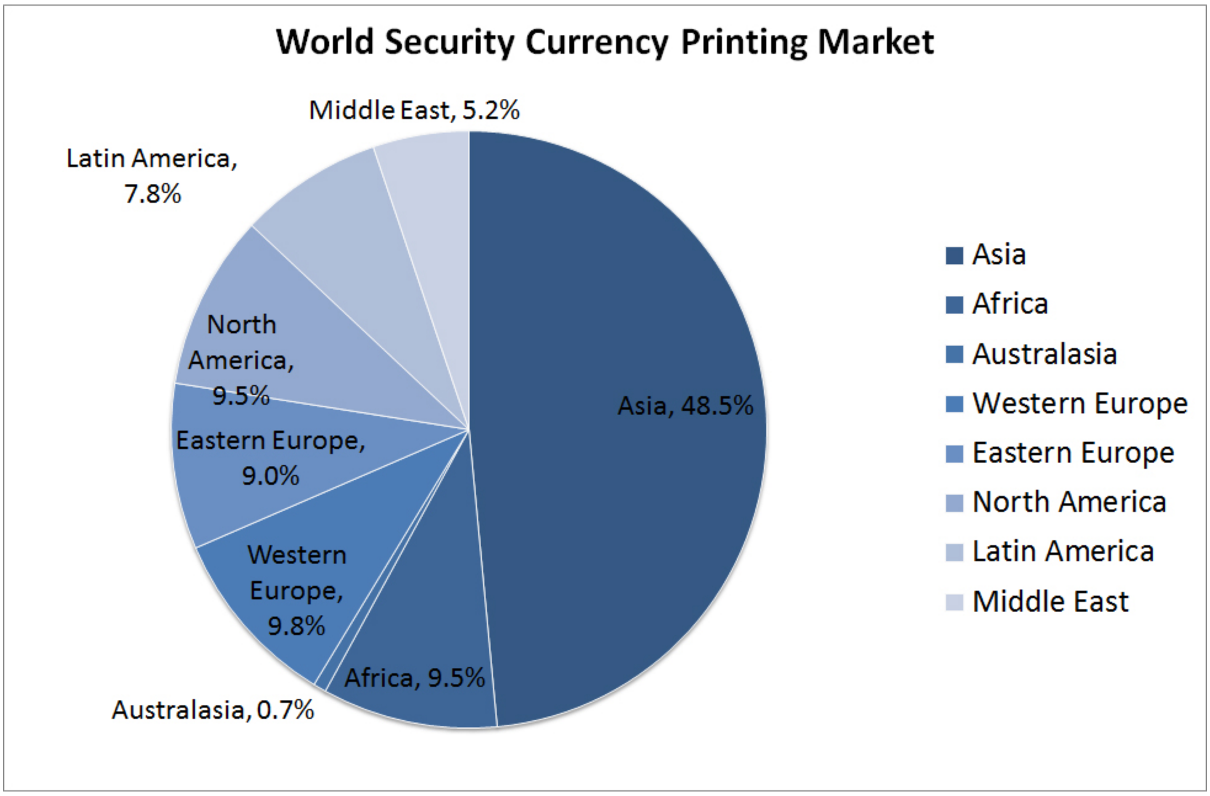


Figure 7 - World Security Printing Market (Smithers Pira, 2013)

As a check, the United States paper currency budget for 2014 is **USD$826.7 million** (U.S. Federal Reserve, 2014). The United States has typically cheaper printed currency, due to their cotton-linen mix as opposed to typically polymer-based security currency. Whilst polymer notes cost twice as much as cotton ones, they last 4 times as long, effectively cutting the whole-of-life costs by 50% (Ahlers, et al., 2010).

Due to their increased defence against counterfeiting, as well as their longevity and lower environmental impact, it is expected that if the world does not go digital with their currency, polymer security notes will take over the cotton-linen market.

Coins

The budget to mint US Coins in 2013 was **USD$459 million** (U.S. Mint, 2014) however, it is difficult to glean a detailed breakdown of these costs. To take the simplest approach, we can multiply the mass of all coins in circulation by the cost to buy the equivalent amount of raw materials, with a 25% premium put in place for the production process.

In 2013, the US used 37240 tonnes of metal to produce coins, of which 90% was copper and 10% was nickel (U.S. Mint, 2014). At a copper price of $7000/tonne and a Nickel price of $16,000/tonne (London Metal Exchange, 2014), this equates to **USD$350 million** in materials. A 25% premium brings it to just over **USD$430 million**, which is close to the official figure of USD$459 million.

Applying this logic to Euro coins which have similar composition, and the very conservative assumption the Euro and USD account for only half of the world's yearly minted coin stock, it can be concluded that international coin minting costs over **USD$1.5 billion** every year.

	Low Estimate Global Production Cost - 2014
Banknote Currency	$26.5 billion
Coin Currency	$1.5 billion
Total	**$28 billion**

Table 8 - Summary Table - Financial Costs of Physical Currency

Environmental Costs of Physical Currency

Again, whilst little globally aggregated data exists, we can analyse data on coins, paper and polymer based notes from the world's major economies. Detailed data exists for the USA, Euro, Australia and Canada.

Paper Currency

A very comprehensive sustainability assessment undertaken by Ahlers et al (2010) attempts to quantify the environmental impacts of the US Dollar, in contrast with polymer-based notes produced in Australia. The major environmental costs, based on data from 2002, are as follows (Ahlers, et al., 2010):

- Water Use During Paper Making: 1 million gallons / day = 1.4 billion litres per year
- Water Use During Printing: 250,000 gallons / day = 0.35 billion litres per year
- Waste Ink & Pulp Sludge = 6 million pounds = 2720 tonnes
- Electricity Use During Printing: 97850 MWH of electricity = 0.35 million GJ
- Electricity Use for Pulp Making = Same as electricity used during printing = 0.45 million GJ
- Ink Usage = 3540 tonnes
- Over 7100 tonnes of cotton
- Over 2300 tonnes of linen

Using the above data, production of US paper notes in 2002 has similar electricity use to the Euro (0.8 million GJ vs 0.87 million GJ), and as the M0/M1 money supplies of both countries grew pretty similarly, it can be concluded that current electricity need to produce all notes in circulation is on par with the Euro at around 4.6 million GJ.

The Euro publishes sustainability statistics on their currency, and according to latest estimates, 3 billion banknotes printed in 2003 had an equivalent energy impact of 460,000 60W bulbs switched on for a year, which equates to 240 million kWh, or 0.87 million GJ. With circulation now at 15.8 billion notes, this would scale up to 4.6 million

GJ (European Central Bank, 2007). To get to a global figure, for the purposes of this report, I will be multiplying this figure by a factor of four (i.e. a proportional share of global M0/M1 money supply). Therefore, we reach a figure of 18.4 million GJ, which would correspond to almost **3.07 million tonnes of CO_2 equivalent**.

Using heuristics from analysis of 100 paper bank notes, the conclusion can be drawn that 200 billion notes produce **3.2 million tonnes of CO_2**, with 100 paper notes producing 1.59kg CO_2 equivalent (PE Americas; Tryskele, 2011). This figure checks well.

	Low Estimate Global Production Cost - 2014
Energy Used	18.4 million GJ
Yearly Water Use	10 billion litres
CO_2 (calculated)	3.2 million tonnes

Table 9 - Summary Table – Environmental Costs of Paper Currency in Circulation

Polymer Currency

Polymer Currency has shown to produce at least 30% less environmental impact than cotton-paper currency (PE Americas; Tryskele, 2011). Due to the relatively small volume of polymer-based currency currently circulating internationally, polymer based currency will not be considered further in this report. As discussed earlier, due to economic, environmental, and social superiority to cotton-paper money, it is likely that over the next generation, all paper money circulating in the world will become polymer based.

Coins

Although there is no concrete data of global yearly minting statistics, data from the EU and US can be extrapolated globally. As a check, you can divide the number of coins currently in circulation in the world, 1.5 trillion, by the average life of a coin, 25 years, to reach a figure of **60 billion coins** minted per annum. For reference, the U.S. mint minted 10.7 billion coins in 2013 (U.S. Mint, 2013), so a global figure of 60 billion is not unreasonable.

Using weight data from earlier sections of this report, the average weight of one million coins is roughly 3.5 tonnes. This means that 60 billion coins will require 210,000 tonnes of metal. Simplifying further and optimistically assuming that coins are 50% copper and 50% steel by weight, and using the carbon emissions data from the table below, we reach a figure of 21.25 million GJ to simply mine the materials used for coin making, not including the energy required for cutting and stamping coins.

Metal	GJ / tonne for mining
Nickel	780
Copper	200
Steel	2.5

Table 10 - Carbon emissions from select base metal mine sites (Farrell, 2009)

Using the GJ to kW to tCO_2 heuristics from earlier in the report, 21.25 million GJ equates to 3.5 million tonnes of CO_2

	Low Estimate Global Production Cost - 2014
Energy Used	39.6 million GJ
CO_2 (calculated)	6.7 million tonnes

Table 11 - Summary Table – Environmental Costs of Cash (Notes + Coins)

Socioeconomic Costs of Physical Currency

Due to its inherent physical and economic properties, fiat currency can be highly advantageous to malevolent actors. Paper money is very easy to counterfeit and launder, and almost impossible to trace and track. Due to its inflationary nature, nefarious types like drug dealers, human traffickers, corrupt public officials and other members of the shadow economy use it as their currency of choice to facilitate their ongoing operations.

The socioeconomic costs of these activities are shown below.

Money Laundering

In 1996, the IMF estimated that 2-5% of the entire world's economy involved laundered money – a figure translating to about $1.5 trillion a year. Whilst this figure seems large, several other experts estimate that the value is closer to $2.85 trillion per year (Smith, 2011). These experts are backed by a 2008 UN report into money-laundering and globalisation which put the figure at anywhere between $800 billion and $3 trillion per annum (UN Office on Drugs and Crime, 2008).

A report by The Council on Foreign Relations translates this dollar figure poignantly into human costs, citing 50,000 deaths in Mexico over the past 6 years due to drug trafficking, as well as the enslavement of 27 million people in forced labour, prostitution, and other activities relate to human trafficking (Council on Foreign Relations, 2013). Social costs of illegal arms trafficking are difficult to quantify, but are no doubt significant.

Seigniorage

As shown in the above calculations, the cost to print money is substantially less than what the money is valued at. The result is inflation / loss of consumer buying power. Global average yearly inflation is 3.9% (CIA World Factbook, 2013), which makes your money worth more than 30% less after 10 years, less than half after 20 years, and 70% less over 30 years, a reasonable estimate for length of a retirement commencing in 2014.

Corruption

In addition to the social damage and the trillions of dollars that money laundering costs the global economy, it is estimated that an additional $1.6 trillion is lost to governments around the world every year (BBC News, 2009) due to corrupt politicians and public officials.

Transactional Fraud

Transactional fraud, mainly through credit and debit cards, cost the global economy a staggering $190 billion per year (LexisNexis, 2013).

Institutional Fraud

The Association of Certified Fraud Examiners estimates the yearly cost of fraud to be 5% of global revenues, or, $3.7 trillion per year, based on 2013 global figures (Association of Certified Fraud Examiners, 2014).

It should be noted that institutional fraud is a problem that is systemic to humans, and not to monetary systems per se. However, as there have been several attacks against the quantity of institutional fraud and scams found in the unregulated world of Bitcoin, it is useful to quantify the magnitude of fraud in the regulated world of corporations. Due to the frequency and magnitude of fraud in the legacy system, I will only refer to single fraud events larger than the largest ever single alleged institutional Bitcoin fraud event (Mt Gox in 2014), so as to not encumber the reader with too many examples.

Biggest Corporate Frauds			
Company	Year	Amount	Source
Lehman Brothers	2008	USD$600 billion	
Enron	2001	USD $78 billion	
Cendant	1997	USD $14 billion	
WorldCom	2003	USD $11 billion	
HealthSouth	2003	USD $1.4 billion	
Biggest Ponzi Schemes			
Company / Individual	Year	Amount	Source
Bernard Madoff	2008	USD $65 billion	
MMM	1990s	USD $10 billion	
Allan Stanford	2009	USD $8.9 billion	
Tom Petters	2008	USD$3.65 billion	
Scott W. Rothstein	2009	USD$1.4 billion	
Enver Hoxha's Albanian Investment Funds	Mid 1990s	USD$1.2 billion + collapse of state	
Chinese Ant Farming Ponzi	2007	USD$1.1 billion	
European King's Club	1994	USD$1.1 billion	

Table 12 - World's Biggest Corporate Frauds and Ponzi Schemes

Theft

Again, it should be noted that theft is a problem that is systemic to humans, and not to monetary systems per se. However, as there have been several attacks against the quantity of thefts found in the world of Bitcoin, it is useful to quantify the magnitude of thefts found in legacy systems. Due to the frequency and magnitude of thefts in legacy systems, I will only refer to single theft events larger or similar in size to the largest ever single alleged Bitcoin theft event (Mt Gox in 2014), so as to not encumber the reader with too many examples.

Theft / Thief	Year	Amount	Source
Stephane Breitwieser	1995 – 2011	USD$1.2 billion	
Iraq Central Bank	2008	USD$1 billion	
Mosul Central Bank	2014	USD$430 million	
Sumitomo Mitsui Hack	2004	USD$423 million	
City Bonds Robbery	1990	USD$400 million	

Table 13 - World's Biggest Theft Events

Further to the above single events, it is estimated that 1.4% of retail revenues, or $112 billion in 2012, are lost to petty theft and shop-lifting every year (Griffin, 2013).

The Black Market

In addition to the more than $3 trillion dollars lost to laundering and corruption, the world's economy is subject to a further loss of $1.8 trillion dollars to the black market. A lot of the money that enters the black market is "clean", i.e., a citizen using legally obtained money to purchase illegal goods. The breakdown of this $1.8 trillion dollar market is shown in the table below (Havoscope, 2014).

Activity	Value ($ Billions)	Activity	Value ($ Billions)
Counterfeit Drugs	200	Art Theft	10
Prostitution	186	Cable Piracy	8.5
Counterfeit Electronics	169	Video Game Piracy	8.1
Marijuana	141.8	Counterfeit Sporting goods	6.5
Illegal Gambling	140	Counterfeit Pesticides	5.8
Cocaine	85	Alcohol Smuggling	5
Prescription Drugs	72.5	Mobile Entertainment Piracy	3.4
Heroin	68	Counterfeit Cosmetics	3
Software Piracy	63	Movie Piracy	2.5
Cigarette Smuggling	50	Metals and Minerals Smuggling	2.3
Counterfeit Foods	49	Counterfeit Aircraft parts	2
Counterfeit Auto Parts	45	Counterfeit Weapons	1.8
Oil Theft	37.23	Kidnap and Ransom	1.5
Human Smuggling	35	International Adoptions	1.3
Counterfeit Toys	34	Counterfeit Watches	1

Activity	Value ($ Billions)	Activity	Value ($ Billions)
Human Trafficking	32	Arms Trafficking	1
Illegal Logging	30	Fake Diplomas and Degrees	1
Methamphetamine	28.25	Book Piracy	0.6
Illegal Fishing	23.5	Nuclear Smuggling	0.1
Wildlife Trafficking	19	Counterfeit IDs and Passports	0.1
Ecstasy	16.07	Counterfeit Money	0.081
Music Piracy	12.5	Organ Trafficking	0.075
Fake Shoes	12	Counterfeit Purses	0.07
Counterfeit Clothing	12	Counterfeit Lighters	0.042
Waste Dumping	11	Counterfeit Batteries	0.023

Table 14 - World Black Market Value - Top 50 Activities

Environmental Impact of the Banking System

It is very hard to quantify the global impact of the banking and finance system, however, there are some key figures that we can draw on for an order-of-magnitude estimate. It is important to note that whilst this can be construed as an apples-to-oranges comparison, it is equally important to get a frame of reference of the huge environmental impact of the banking industry, and to illustrate that we must ensure that we avoid having the same negative impact as we have in the past, should Bitcoin be successful and scale to the size of the existing system

The World Bank publishes several world development indicators, of which one is financial access. The below table shows their data and associated estimate calculations (World Bank, 2014), based on a world adult population of 5.325 billion people (Indexmundi, 2013).

Financial Access Point	Number per 100,000 adults (World Average)	Rationalised Number
Bank Branches	11.7	591,075 branches
ATMs	34.21	2,394,700 ATMs

Table 15 - World Bank Financial Access Data - 2014 (World Bank, 2014)

A model developed by the CoolClimate Network at one of the world's leading and most respected universities, The University of California, Berkeley (CoolClimate Network, 2014), assesses the carbon footprint of businesses based on business sector, the number of locations, employees, annual revenue, and square feet of facilities allows us to estimate the carbon footprint of the world banking and finance industry within an order of magnitude. Inputs into the model are calculated below.

Bank Branches

Model Inputs

Number of Employees

While it is difficult to quantify the number of people employed by the world's banking and finance industry, using the Pareto Principle (80/20 rule), the world's largest 20% of banks most likely employ 80% of all banking employees. Employee statistics for the world's largest 30 banks are shown in the table below.

Bank Name	No. Employees	Source
Agricultural Bank of China	444238	abchina.com
Industrial & Commercial Bank of China	405354	www.icbc.com.cn
China Construction Bank	329338	www.ccb.com/en/home/index.html
State Bank of India	295696	www.sbi.co.in
Bank of China	288867	www.boc.cn
Sberbank	286019	www.sbrf.ru
Wells Fargo & Co	264900	www.wellsfargo.com
JP Morgan Chase & Co	255041	www.jpmorganchase.com
HSBC Holdings	254066	www.hsbc.com

Bank Name	No. Employees	Source
Citigroup Inc.	251000	www.citigroup.com
Bank of America	242000	www.bankofamerica.com
BNP Paribas	200000	www.bnpparibas.com
Banco Santander	186763	www.santander.com
Société Générale	171955	www.societegenerale.com
Crédit Agricole Group	161280	www.credit-agricole.com
Unicredit Group	148341	www.unicreditgroup.eu
Barclays PLC	139900	www.barclays.com
Banco do Brasil	118900	www.bb.com.br
Royal Bank of Scotland Group	118600	www.rbs.com
Group BPCE	115000	http://www.bpce.fr/en/
BBVA	109305	www.bbva.com
Lloyds Banking Group	104000	www.lloydsbankinggroup.com
Banco Bradesco	103385	www.bradesco.com.br
Deutsche Bank	98219	www.db.com
ING Group	84718	www.ing.com
Mitsubishi UFJ Financial Group	80900	www.mufg.jp
Royal Bank of Canada	80000	www.rbc.com
Bank of Communications Limited	79122	www.bankcomm.com
Toronto-Dominion Bank	78748	www.td.com
US Bancorp	65565	www.usbank.com
TOTAL	**5561220**	

Table 16 - Number of People Employed by the World's 30 Largest Banks

Assuming that the 5,561,220 figure in the table above represents 80% of all bank employees, it can be concluded that there are a total of at least **7 million people** employed by banks and financial institutions internationally.

Annual Revenue

An analysis undertaken by McKinsey & Company in 2012 shows global banking revenue of $3.4 trillion (McKinsey & Company, 2012).

Square Foot Area of Facilities

From personal experience designing offices in Australia, a good rule of thumb is 10m^2 per employee (about 100 square feet) to satisfy access and egress requirements in commercial building codes. An area of 50 – 150 ft^2 is recommended by US Engineering site, Engineering Toolbox (Engineering Toolbox, 2013). Using a value of 100 ft^2 leads to a total area of about 60 million ft^2 for the world's 600,000 bank branches.

Model Output & Sensitivity Analysis

Plugging the above 4 inputs into the UCB Model yields a result of 383.1 million tonnes of CO_2/year. A sensitivity analysis showing 4 other scenarios shows little difference in overall footprint. Because the data on revenue is accurate, that variable remains fixed in all scenarios.

	Base Case	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Branches	600,000	550,000	500,000	600,000	600,000
Employees	7 million	6 million	6 million	8 million	9 million
Revenue	3.4 trillion	3.4 trillion	3.4 trillion	3.4 trillion	3.4 trillion
Square Feet	60 million	50 million	40 million	60 million	60 million
Tonnes of CO_2	383.1 million	380.4 million	380.3 million	385.7 million	388.2 million

Table 17 - Model Outputs & Sensitivity Analysis - Global Banking Carbon Footprint

As can be seen from Table 17, the governing factor of the model appears to be the amount of yearly revenue generated, as significant changes to number of employees and branches have little effect on the model output.

Sense Check

The World Resource Institute categorises World Greenhouse Gas Emissions by end-use and activity (World Resources Institute, 2009). In their 2009 report, it was identified that Commercial Buildings account for 6.3% of world emissions, and the mining of non-ferrous metals (including Gold) and aluminium account for 1.3% - an impact ratio of commercial buildings to mining of 4.86.

Considering that only a relatively small amount of Gold is mined every year (a few thousand tonnes), it is assumed that banks account for larger proportion of all commercial buildings, as gold mining does for non-ferrous metal mining. This would mean that banks should have an impact of between 6-8 times greater than that of gold. Having calculated a value of 54 million tonnes of CO_2 produced by the gold mining industry, this would put the impact of the banking industry between 324 and 432 million tonnes of CO_2, which is well within the same ballpark as the value of 380 million tonnes calculated by the UCB model.

ATMs

While ATMs reduce the need for bank branches, these machines have their own carbon footprint which isn’t insignificant.

It is estimated that each of the world’s 2,394,700 ATMs has an energy usage of 0.25 kWh (Roth, et al., 2002). This translates to a yearly energy use of 18.9 million GJ, or 3.2 million tonnes of CO_2.

Summary

The environmental impact of the world's financial access points are summarised in the table below

Access Type	Impact (million tonnes CO_2 / year)	Energy Use (GJ)
Bank Branches	383.1	2.3 billion
Automatic Telling Machines	3.2	18.9 million
Total	**386.3**	**2.3 billion**

Table 18 - Summary of Impact of World's Banking and Finance Access Points

Using the rate of $100 / MWh, the above energy use would equate to an annual energy bill of $63.8 billion, or, roughly 2% of total revenue. To give the reader a broader idea of the efficiency of the banking system, banks typically have an overall expense-to-income ratio of over 55% (Federal Reserve Bank of St. Louis, 2011), i.e. overall expenses of 0.55 x 3.4 trillion = $1.87 trillion

The Bitcoin Network & Bitcoin Mining

Introduction

Bitcoin mining underpins the Bitcoin network, and is the most fundamental aspect of the Bitcoin network, as the mining process both verifies and logs transactions, as well as generates new Bitcoins.

In order to assess the environmental, social, and economic costs of Bitcoin requires a review of the fundamental economics of bitcoin mining, as well as a review of the state of the art of mining technology, and its exponential rate of improvement. This section will discuss Bitcoin mining's macro and micro economic context

The landscape of the Bitcoin mining industry is very dynamic, and has experienced significant evolution since the network was created in January 2009. It is a perfectly competitive market, and anyone in the world can join it due to the lack of significant barriers to entry.

All calculations throughout have not been rationalised by market-cap of Bitcoin, as it is uncertain if Bitcoin will ever scale, and if it does, it is almost certain that mining equipment will exponentially increase in processing efficiency in line with Moore's Law for at least another decade (Hruska, 2013), and exponentially increase in power efficiency in line with Koomey's Law for at least another 30 years (Koomey, et al., 2010).

Brief History and the Evolution of Bitcoin Mining

Similar to gold mining, over time, Bitcoins become relatively harder and more expensive to mine. Just as several people found success panning for gold during the California Gold Rush of the 1840's, making any money in the gold mining industry in 2014 requires multi-billion dollar infrastructure and equipment, and highly specialised technical skills and knowledge, as seen in the timeline below.

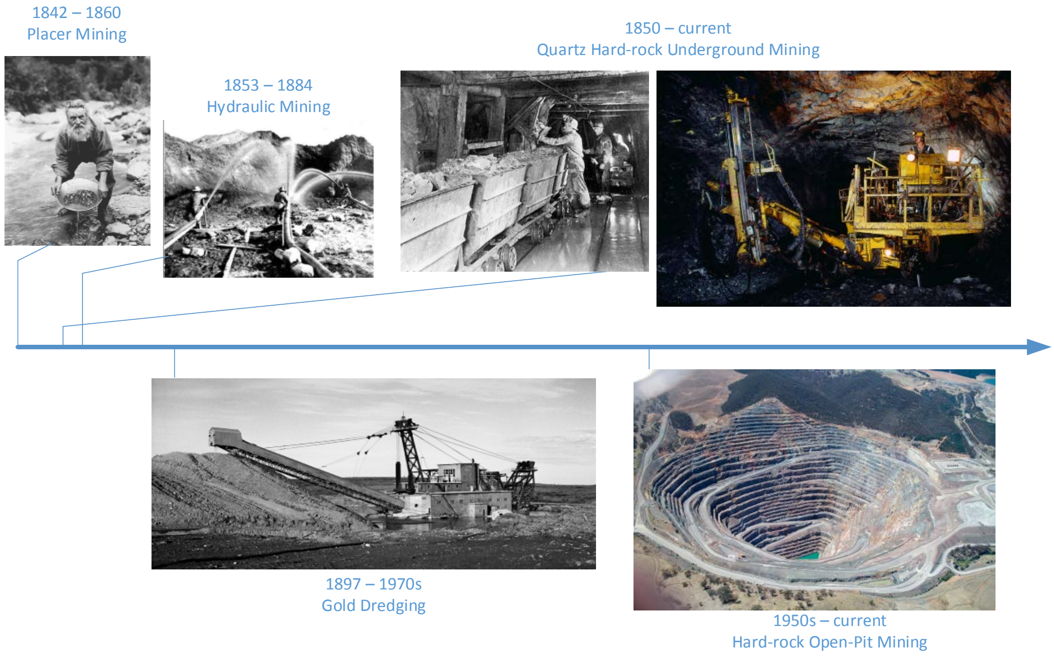


Figure 8 - Gold Mining Techniques - Infographic Timeline (Tuolumne County Historical Society, 2000)

Mirroring this evolution, in the very early days of Bitcoin, an ordinary home PC could mine hundreds of Bitcoins per day, but at the time of this writing, a $10,000 piece of hardware known as an Application Specific Integrated Circuit (ASIC) will only mine fractions of a Bitcoin per day. This is because Bitcoins are mined when a complicated algorithm is solved and transaction block generated, typically every 10 minutes. When network hashrate increases, algorithms are solved faster; when network hashrate decreases, algorithms are solved slower. The Bitcoin network self-regulates by increasing the difficulty of solving the algorithm to ensure that a new transaction block is generated every 10 minutes. This self-regulation occurs at 2016 block intervals, or, about two weeks, give or take an amount of days directly inversely proportionate to the change in network hashrate (e.g. if the hashrate goes up 10%, it 12.6 days to complete a cycle; or; if the hashrate goes down 20%, it takes 16.8 days)

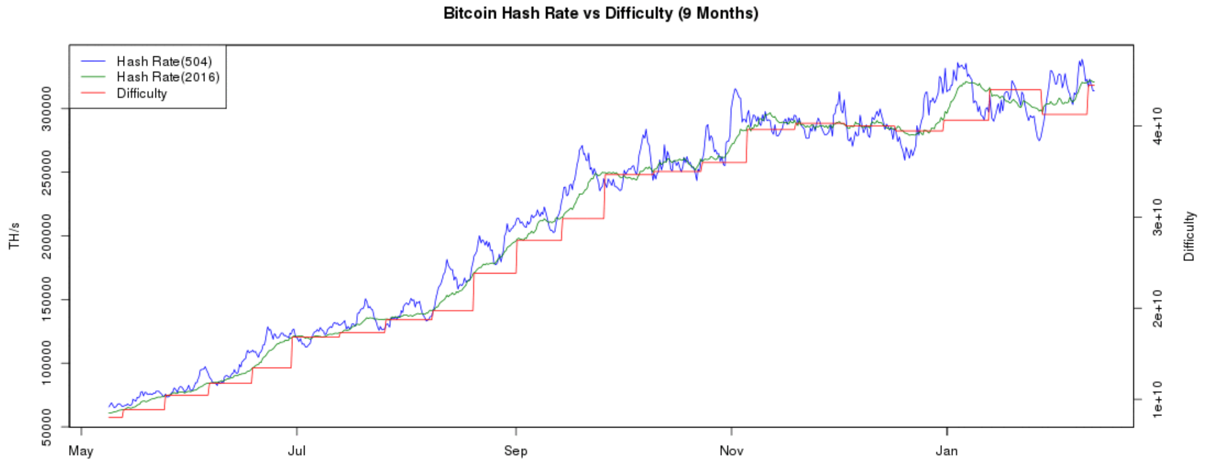


Table 19 - Bitcoin Hashrate vs. Difficulty – May 2014 – February 2015 (BitcoinWisdom, 2015)

Since October 30 2012, the network hashing power has increased exponentially from 23,645 GH/s to over 295,000,000 GH/s as at the January 26 2015, a growth of over 12, 00 times (BitcoinWisdom, 2015).

The bitcoin mining industry has so far seen three generations of evolution in mining techniques; home Computer Processing Unit (CPU) mining, followed by home Graphics Processing Unit (GPU) mining, and most recently, Application Specific Integrated Circuit (ASIC) mining. Although there is no evolutionary technology on the near-term horizon, there is still great potential in the $/Computation and Computations/Joule of Energy performance of ASIC units based on the principles of exponential acceleration of technological improvement. To demonstrate the exponential recent improvements, the below table shows the state of retail mining system efficiencies in July 2014 and January 2015 (BitMain, 2015) (Bitcoin Wiki, 2014)

	June 2014	January 2015	% Change
Network Hashrate	100,000,000 GH/s	295,000,000 GH/s	**+ 295%**
Retail-Best Miner	Cointerra Terraminer IV	Bitmain Antminer S5	
$/GH	$2.99	$0.2925	**- 90.1%**
W/GH	1.1	0.51	**- 53.6%**

Table 20 - ASIC Performance - June 2014 - January 2015

Although these figures do not paint an absolute story about mining cost, it can be seen that, holding the assumptions of supply and demand constant, improvements in mining efficiency have dramatically outstripped increases in network hashrate (and subsequently, associated difficulty increases). In times of waning demand such as those that have been witnessed in the past 7 months, this would theoretically drive market price of bitcoin down due to the assumption that in a state of perfect competition (discussed in a later section of this report) miner profit is maximised when marginal revenue equals marginal cost i.e. when cost to mine a bitcoin is about the same as the cost to buy one on the open market.

The extreme performance improvements seen over the past 7 months are anticipated to continue over the next few years, with the CEO of Spondoolies Tech, a leading Bitcoin Mining ASIC maker, stating the following in a December 2014 interview; "*"Our goal is to get to 0.05 W/GHs, 0.03 $/GHs miners by mid-2015 and power more than 30% of the bitcoin network," Corem explained, adding that he believes these figures will help the company match its rival firms in the US and China*" (Rizzo, 2014)

Macroeconomic Drivers of Commodity Mining

Without trying to complicate things too much, we will look at the very broad, all-encompassing, tried-and-true forces of supply and demand to illustrate bitcoin in action in its natively competitive ecosystem.

Demand

Applying the "digital gold" analogy to Bitcoin, the majority of demand from bitcoin stems from investment and speculation, market applications (bitcoin commerce, payment processing, broker/exchange, etc.), and industrial applications (smart contracts, proof-of-work, blockchain applications and development, etc.). Unlike gold however, it is very difficult to find data on the exact sources of demand in the Bitcoin world, not to mention the strength of each of their forces. These forces will be looked at in detail in the section on Competitive Strategy & Managerial Economics. See Figure 1 for data on gold.

Supply

Bitcoin's supply is controlled by protocol, with a supply approaching a fixed point at a reasonably well known pace. The supply of bitcoin is currently kept stable by the protocol at 25BTC per block; at a rate of one block mined, *or, solved*, every ten minutes or so. After 2016 blocks are mined, which should typically take two weeks (2016 x 10min = 2 weeks!), their average time between blocks is evaluated in comparison to the previous 2016 blocks. Depending on whether time between blocks has increased or decreased, the level of difficulty to mine a block resets so that time between blocks is returned to 10 minute so that the cycle remains about two weeks long. Hashrate and network difficulty are directly proportional, i.e., 10% increase in hashrate = 10% increase in difficulty, and vice versa.

Difficulty is driven by the Bitcoin's Total Network Hashrate, the combined processing power of all miners in the network. When more mining hashing power is brought online, the network's total hashrate increases, leading to quicker average block solutions. When hashing power is taken offline, the opposite happens, leading to long times between solutions. This means that the supply of bitcoin is at constant flux around the magic 10-minute figure, with the average "two week cycle" taking 12.37 days +/- 1.32 days over the past 88 difficulty cycles since January 2012 (BitcoinWisdom, 2015) – slightly ahead of supply schedule. There can be market shocks, such as when a new generation of mining equipment comes online, or when there is an outage of some sort which takes down several nodes, that affect supply in the short term, long-term supply is easy to predict.

Every 210,000 blocks mined, the reward for solving a block halves. This should happen once every 4 years or so, and can be referred to as the reward cycle. The next reward halving is set to occur sometime in July 2016, which will reduce the supply to 12.5BTC/10mins (then 6.25 in 2020, 3.125 in 2024, 1.5625 in 2028…). The current reward cycle is expected to last well below four years, due to exponential hashrate growth – an average of 13.21% growth fortnight-on-fortnight, with a standard deviation of 11.63%, since January 2012. This is illustrated in the graph below.

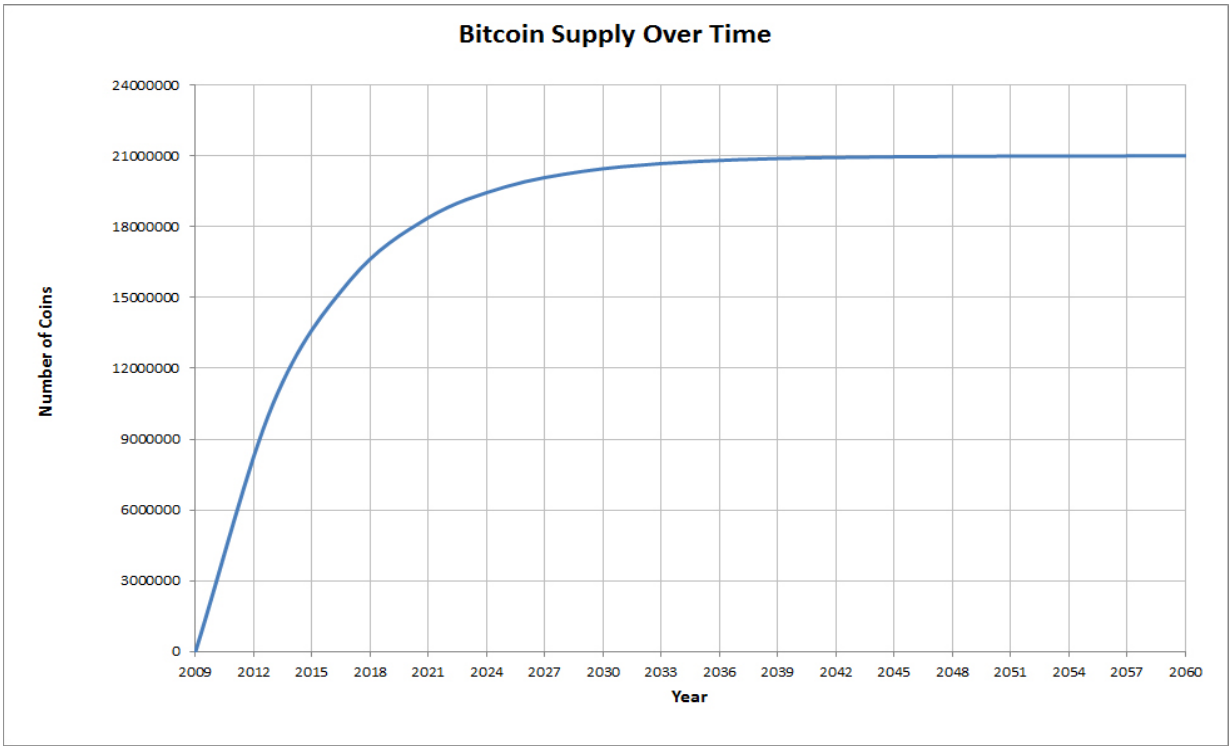


Figure 9 - Bitcoin's Controlled Supply

Interaction of Supply & Demand in the Bitcoin Ecosystem

Regardless of where demand for a particular good comes from, if demand does not keep up with supply, the market value of said good drops until it finds a market demand. In the opposite case, the market value of said good increases until demand is satiated.

Using idealised assumptions of long-term equilibrium in the context of a random easy to access commodity good, commodity price will find equilibrium with supply cost, and profits will tend to zero.

As demand (and hence typically price) increases, more people will want to supply it to gain short term profit. Eventually, all profits will be eroded away by competition. For bitcoin, as more miners come online, the hashrate increases along with the difficulty. As the entire network grows, an individual miner's piece of the total pie decreases. For the individual firm to maintain its total share of rewards, it would need to grow itself on a fortnightly basis in proportion with the network. It is also the same in the opposite scenario. This phenomenon will form the basis of forward-looking CAPEX planning for mining operators.

As demand fades, some suppliers will eventually go out of businesses due to lower sale prices (but similar fixed investment and operational costs), with the innovative cost-leaders remaining profitable enough to stay in business to whether the wild fluctuations in demand witnessed in the Bitcoin ecosystem.

In real-world commodity markets, large commodity producers are able to arbitrarily control supply to a strategic advantage, either as individual firms, or in a cartel, which introduces volatility into commodity prices.

In the case of bitcoin in its current state, it is the opposite. Supply is fixed, but demand can be somewhat manipulated through market actions of speculators and investors i.e. price-makers. In long-term equilibrium however, there are only price-takers, thanks to the nature of perfect competition, which will be discussed in the next section.

Nature of Competition in the Bitcoin Ecosystem

Market competition comes in many forms; monopoly, oligopoly and perfectly or monopolistically competitive. While it is very rare to see a perfectly competitive market in practice due to the existence of regulations, due to its open-sourced, commodity nature, a strong case could be made that Bitcoin is practically perfectly competitive in the long term, and almost perfectly competitive in the short term. There are several factors that may cause a market to be perfectly competitive and a very concise and comprehensive 5,000 word summary synthesis of several economics textbooks and academic journal publications on Perfect Competition can be found on the Perfect Competition Wikipedia page (10-15 minute read). I will attempt to summarise the summary, as well as present the short-term and long-term case for the Bitcoin economy being a perfectly competitive one, in under 500 words. Orange table cells indicate imperfections which violate the theoretical definition of perfect competition, whereas the green cells signify compliance with the definition.

It is important for the reader to note that markets are in a permanent state of short-term equilibrium, but asymptotically tending towards long-term equilibrium. This state of equilibrium has applied to all failed and successful industries throughout history, and will apply to all industries in the future.

Market Characteristic & Definition	Application to Bitcoin (short-to-medium-term: 0 – 3 years)	Application to Bitcoin (long-term: 3 years+)
All market participants are "price takers"	"Temporary price makers" dump / buy vast amounts of coins on an exchange, causing dramatic instantaneous negative/positive price movement, respectively. Once done however, market power and future effects are proportionately permanently reduced by the amount of coins that were dumped / bought.	As bitcoins become less concentrated due to inherent scarcity, the gross majority of all market participants will become price takers
Profit Maximisation	Miners will sell at the intersection of Marginal Cost and Marginal Revenue, except during hype cycles, where sales strategy differs wildly across the industry	Miners will sell at the intersection of Marginal Cost and Marginal Revenue
Perfect Factor Mobility	Factors of production (Location, Labour & Capital) are almost perfectly mobile, allowing for adjustments to changing market conditions	Factors of production are perfectly mobile in the long term
A Large number of buyers and sellers	There is currently only a relatively small number of buyers and sellers compared to traditional markets, however, this number is increasing exponentially in an analogous way to other network-effect based disruptive technologies	Large number of different types of buyers and sellers (investors, merchants, exchanges, remittance, etc.)
Zero transaction costs	Transactions are theoretically free – but free transactions are subject to the possibility of delays. Fees are not set by the market, and are voluntary based on desired transaction speed.	Transaction costs will be near zero

Market Characteristic & Definition	Application to Bitcoin (short-to-medium-term: 0 – 3 years)	Application to Bitcoin (long-term: 3 years+)
Non-increasing returns to scale	Non-increasing returns to scale when an individual miner or pool of miners approach 50% of network power. There are huge disincentives to exceed 50% of network hashing power.	Non-increasing returns to scale
No externalities	The only externalities are emissions due to proportion of network using fossil-fuels to provide electricity for mining, and waste produced by obsolete mining equipment. Externalities are discussed in more detail later in this report.	Externalities asymptotically trending to zero due to decentralised renewable energy, and improvements in recycling
Perfect Information	In the short term, “Price Makers” prevent the overall market from having access to perfect information as they can individually influence market price at an arbitrary point in time, and/or they are privy to material and non-public information.	Due to the open-source nature of Bitcoin, in the long term, all consumers and producers are assumed to have perfect knowledge of price, utility, quality and mining methods.
Homogeneous Products	All bitcoins are homogenous and identical for the gross majority of practical intents and purposes, and will always be.	
Property Rights	The Blockchain ensures that there is no doubt about ownership of Bitcoins and their owner’s rights, and this will always be the case	
No barriers of entry and exit	No onerous barriers to entry or exit can by created by incumbents to restrict competition due to Bitcoin’s open-source and global nature, and impracticality of unified global regulation or licencing requirements, and this will always be the case. Starting capital and intellectual property are the only real barriers to entry.	

Table 21 - Bitcoin as a Perfectly Competitive Market

Competitive Strategy & Managerial Economics

Now that we have established that Bitcoin is a potentially perfectly competitive ecosystem, we can illustrate how mining operators may form managerial strategy. Using a market analysis framework like the Porter's 5 Forces (Porter, 1980) we can further illustrate the perfectly competitive nature of the Bitcoin industry, and begin to identify drivers of operational and capital costs. Several strategy academics and consultants also consider a sixth force, strength of collaborators and complimentary products, which is an especially important force in highly competitive open-source industries.

Current State

Figure 10 - Porter's 6 Forces Analysis of Bitcoin Mining Industry

Industry Competitors

There are three major types of competitors in the bitcoin mining industry; fabricator-miners, retail miners, and cloud miners. Retail miners can be further broken down into large-scale retail miners, and at-home hobbyist retail miners. Fabricator-miners design and manufacture ASIC chips, mine with them, but also sell mining units to retail miners for a profit. Competition amongst and within the three groups is cut-throat. The most successful miners are the ones with the lowest cost base and the best brains getting the newest ASICs online quicker than their competitors.

Retail miners can be defined as businesses or individuals that purchase mining equipment from fabricators and mine at a location that is most favourable to them. Retail miners can choose to mine individually or cooperate with a pool of other miners whereby profits are split up based on the proportion of hash power each individual brings to the pool.

Cloud miners are typically businesses with large amounts of hash power, and on-sell cloud-based hash power to consumers. Cloud mining allows consumers to mine bitcoin without having to manage and maintain hardware, however, a hefty price premium is typically paid by the consumer for this luxury, with typical $/GH rates being significantly higher than a retail ASIC.

Threat of New Entrants / Barriers to Entry

There are almost no barriers to entry to bitcoin mining, however, barriers to becoming a successful miner do exist. These barriers are the possession of intellectual property and expertise, and the requirement for continued capital expenditure. To that end, there is a medium-to-high threat of a superior competitor entering the market and taking market share away from the incumbents.

Bargaining Power of Suppliers

The main suppliers in the bitcoin mining industry are:

- Electricity Providers
- Data Centre Providers / Data Centre Supplies Suppliers
- Speciality Hardware Manufactures

Due to most of the suppliers in the industry being natural monopolies / oligopolies (energy providers and hardware manufacturers) suppliers have very high power over miners. With that said, due to the principles of perfect competition and perfect factor mobility, miners are free to find the cheapest electricity rates in the world and choose to mine there.

Bargaining Power of Buyers

A buyer in the bitcoin space is basically anyone who wants to buy bitcoin. Due to the very high number of different miners that customers can buy from, miners do not have much power over buyers, and can’t justify charging overly high premiums for their mined coins. Also, due to extreme volatility in demand, miners have to sell their bitcoins whilst they know that a market for their product exists at least at their breakeven point to manage their risk.

Typical buyers are retail investors & speculators, institutional investors & speculators, and market makers (brokers, exchanges, etc.).

Collaborators / Complimentary Products

The Bitcoin System is highly collaborative and complimentary. A highly successful firm in a particular niche will increase the value of the whole ecosystem, so, even the proprietors of failing bitcoin companies can realise huge fiat-currency-measured success due to the success of their competitors and collaborators.

Due to the nature of perfectly competitive markets, it is only possible for firms to make profit in the short term, and only by innovating and reducing their cost base. To that end, Bitcoin firms should focus on innovation above all else, and try to collaborate more than try to compete. After all, in the words of John Maynard Keynes, these firms will all be dead in long-term equilibrium, as bitcoin was essentially designed to be peer-to-peer, and, if bitcoin ever reaches its potential, there will be practically no use for any bitcoin firms, although there will be several firms that fill market niches and survive.

Bitcoin mining collaborators include brokers, exchanges, investors, media and advertisers, wallet providers, and general bitcoin service providers. Basically, any firm that can increase the utility of bitcoin as a commodity is directly benefiting the overall mining industry.

Threat of Substitute Products

Bitcoin, or rather, distributed finite digital currencies in general, may be considered a substitute product for the legacy financial system due to their wildly differing nature, but similar functionality and utility in the long term. Due to the significance of the discovery of the blockchain, it is unlikely that there will be a substitute product to unseat cryptocurrencies, however, there is a threat of a competing cryptocurrency unseating Bitcoin, with other crypto miners taking away market share from bitcoin miners.

Trends

Current Short-to-Medium-term Trend (0-3 years)

Based on current relative lack of international adoption of bitcoin, and the equilibrium move to 20nm architecture, we can expect to see steady growth in hashrate and network difficulty of 10-15% per fortnight. For reference, of the 78 difficulty changes between 22 January 2012 and 31 August 2014, average difficulty increase was 14.27% +/- 11.80% (BitcoinWisdom, 2015).

Long-term trend (3 years+)

Although it is apparent that the days of Moore’s Law of number of transistors doubling on a circuit-board every 18 months are coming to an end due to size constraints of silicon atoms (10 nano-meters), it is not expected that Moore’s law will come to an end for another 6 or 7 years (Hruska, 2013), so this research will need to be revisited when there is a paradigm-shifting step-change in processing speed and energy efficiency. As can be seen in Table 20, future technology will make huge strides in efficiency and price per GH. In addition to Moore’s Law, Koomey’s Law (Koomey, et al., 2010), a law which has been accurate since the 1950s, and by which, according to the Landauer Principle (Landauer, 1961) and Second Law of Thermodynamics is expected to hold until 2048 when 99% of all Bitcoins are mined, energy needed for a fixed computing load halves every 18 months i.e. a factor of 100 every decade.

The Rule of Three

Bruce Henderson hypothesised that in a competitive marketplace, there is a natural tendency for the market to be dominated by three or four players – known as "The Rule of Three" (Henderson, 1976). This hypothesis was tested and supported by Sheth and Sisodia, who observed the evolution of roughly 200 competitive markets (Sheth & Sisodia, 2002). According to their research, it is almost impossible for an oligopoly or monopoly to continue to dominate a competitive market in the long-term, not least a perfectly competitive market such as Bitcoin. The only times disruption to oligopolies and monopolies does not happen and when The Rule of Three does not apply is when the following conditions exist in a market:

1. Regulation hindering competition
2. Exclusive rights
3. Major barriers to entry
4. Markets with combined management and ownership

These conditions simply do not exist in the bitcoin economy. Therefore, in the long-term, as huge chip makers similar to Intel or AMD focus on mass-consumer production of ASIC mining equipment, the industry will most likely be dominated by 3 or 4 large pools, who each are powered in a reasonable part by individual private miners.

Naturally, the most competitive and profitable mining pools will be those set up in jurisdictions with the cheapest electricity, as well as access to cheaper-than-competitor bulk hardware.

Vertical & Integration

Vertical integration is when a firm makes acquisitions upstream (suppliers), downstream (customers), or a mix of both. Horizontal integration is when a firm acquires a competing or collaborating firm. The laws of perfect competition allow us to predict that in long-term equilibrium, there will be 3 or 4 very highly integrated bitcoin companies, and a very large number of niche players.

An example of a fully integrated Bitcoin company could be a mining hardware manufacturing company that supplies liquidity to an exchange that it operates in order to accommodate retail and institutional buyers, processes payments to provide more liquidity to the exchange and to service merchants, and which also provides both a physical and online wallet service. This company could also manufacture solar panels or other means of renewable energy to keep their ASICs powered at the absolute lowest market rate.

Coinbase is one of the very few highly-integrated bitcoin companies in the ecosystem, and they currently provide a brokerage service, an exchange, payment processing, and a highly secure online wallet (Coinbase, 2015). There is very little mystery as to why they have received a $400m valuation after three of the largest VC funding rounds in Bitcoin history (Kharif, 2015).

Conclusion

The mining cycle is difficult to interpret since it depends on the market price of Bitcoin. Similar to large gold miners, when market price of the underlying asset drops, miners tend to hold their assets to restrict supply, causing an eventual increase in price. Miners who can't afford to do this typically shut off their equipment, and exit the mining game.

When market price increases, this draws more miners into the game, increasing network hashrate and difficulty, which requires further capital expenditure from incumbent miners, which also leads to higher operating costs. So long as market price exceeds mining cost, miners will enter the market, and so long as mining costs exceed the market price, miners will either leave the game, or withhold supply – just as physical commodity miners do.

Difficulty increases have been fairly consistent over the past two years, with typical fortnightly hashrate increases of between 10 and 20% (BitcoinWisdom, 2015). Because of this, the useful life of most mining equipment is only about 3 to 6 months.

Calculating the Costs

Calculating the costs of Bitcoin can be modelled quite simply through the relationship of the 7 variables detailed below.

Model Inputs

CAPEX

CAPEX is the capital expenditure required to maintain a proportional share of mining rewards upon an increase in difficulty. This is typically the purchase of additional GH/s at a particular $/GH rate. As mentioned earlier, over the past 88 difficulty changes over the past 2 years, miners have had to increase their individual hashrates by 13.21% +/- 11% every fortnight to keep their BTC revenue consistent.

OPEX

OPEX is the expenditure required to remain operational. At scale, this is effectively just the cost of power.

Time Period

The time period used to calculate the cost of mining a bitcoin will be the average time between difficulty changes, which for the past 2 years, has been about 12.37 days as mentioned earlier.

Coins Mined

This is a fixed number – there are 2016 blocks of 25 bitcoins mined every difficulty cycle – 50,400 bitcoins. There is also a few hundred bitcoins in mining fees generated every fortnight

Power Cost

As calculated previously in this report (see Table 3), the world weighted average cost for electricity is $0.1/kWh. It can be assumed that the average international retail miner mines at this cost, and that due to perfect factor mobility and economies of scale, chip-fabricator miners pay considerably less. For the purposes of this illustrative calculation, I will assume a rate of $0.07/kWh, which is the average rate for US industrial companies (Asciento & Lawrence, 2013) although there are several documented cases of the largest bitcoin mining operations paying $0.04/kWh, with one particular CEO claiming a cost of electricity of only 1.7 cents/kWh for their mining operation in Moses Lake, Washington, USA (Clenfield & Alpeyev, 2014).

Mining Mix – "The Network Average Miner"

As mentioned earlier, there are three types of miners; chip-fabricator miners, retail miners, and cloud miners.

With one of the world's largest cloud miners, Cex.io, declaring that they could not make a profit at current price levels, and its largest competitor PBMining being proven to be a Ponzi Scheme, it can be assumed that the amount of cloud hosted hash power on the network is negligible.

This leaves retail miners and chip-fabricators. Typical profit margins in the semiconductor fabrication industry are in the area of 15-25% (Ro, 2012), and chip-fab miners would be able to achieve economies of scale with power and data centre costs. It can therefore be assumed that chip-fabs can mine for up to 30% cheaper than retail miners, and that they form the vast majority of the network's hash power. There have been reports from large chip-fabricator KnC Miners that in 2015, they won't be selling any retail products at all, instead using the $5m of Venture Capital raised to run their own chips (Chernova, 2014). In theory, the Pareto Principle (Pareto, 1896), or, 80-20 rule, would lead us to expect that 80% of units sold go to 20% of the customer base, and these customers would typically buy in bulk a small discount. This is backed up by market data from Ravi Iyenegar, founder and CEO of large ASIC fabricator CoinTerra, who said in an interview with Coindesk's Danny Bradbury (Bradbury, 2014), *""The ratio of small retail miners to institutional miners has gone down," said Iyengar, adding that now, fewer than 20% of the units CoinTerra sells go to people mining from home."* Adam McKenna, founder of mining pool Multipool, told Bradbury in another interview that "*home hobbyist miners are almost always behind the curve, putting cash down for a unit that won't ship for months, in a market where every day matters*".

Due to the laws of perfect competition, it can be assumed that only the most profitable miners are switched on at any given time, and that when a new generation of mining equipment is released, equilibrium is reached very quickly where all miners are operating at a similar cost basis.

	Retail Best	Chip-Fab Best	Weighted Average
$/GH	$0.2925	$0.22	$0.234
W/GH	0.51	0.38	0.408
$/W	$0.10	$0.07	$0.076
% of Network	20%	80%	

Table 22 - Rationalised Weighted "Network-Average" Miner

Network Hashrate

As at the date of this report, total network hashrate is 290,000,000 GH/s (BitcoinWisdom, 2015).

Calculation Steps

CAPEX

Since average increase in hashrate is about 13%, in the next difficulty cycle, miners will have to bring a total of 13% x 295,000,000 GH/s = 38,350,000 GH/s online to ensure they. At a weighted average cost of $0.234/GH/s, this is about $8,973,900 per cycle, or, $269,363,133 per year assuming all variables are frozen at this point in time for one year.

OPEX

Based on actual data, average difficulty cycle time is 12.37 days, or 297 hours. At a weighted average of 0.408W/GH, there is a total of 0.408W/GH x 295,000,000 GH/s / 1000W/kW x 297 hours = 35,746,920 kWh. At a weighted average cost of $0.076/kWh, this gives $2,716,765

Adding CAPEX and OPEX gives $11,690,665 spent per cycle. This expenditure yields 50,400 bitcoins per mining cycle. Dividing the two gives an average cost of about **$232**, with the best miners in the world mining at a cheaper rate, and the less efficient miners mining at a considerably higher cost. In contrast, 1 Bitcoin traded between USD$254.67 - $309.99 on the Bitstamp Exchange on January 26, 2015, closing at USD$274.

Although this is not a precise figure, undertaking a sensitivity analysis using different realistic assumptions will yield a similar result – that is – in medium term equilibrium (i.e. when things are in a lull), the cost to mine a bitcoin is very close to the price of a bitcoin. This is no surprise, as the laws of perfect competition tell us that marginal revenue is equal to margin cost in the equilibrium state.

Environmental Costs of Running the Bitcoin Network

With a network hashrate of 295,000,000 GH/s, the network needs 0.408 x 290,000,000 Watts = 120,360 kW. This equates to 120,360 kW x 24 hrs/day x 365.25days/yr = 1,055,075 MWh / year.

This equates to 3.97 million GJ/year, and 660,000 tonnes of CO_2 / year.

At $100/MWh (Table 1), this electricity would cost $105,507,500 / year.

Although the Bitcoin mining industry should be efficient in theory, and the largest miners would be expected to have the most efficient equipment, this is not easily provable. The difference between the most efficient and least efficient miners is quite clear, and it makes sense that the large professional miners continually reinvest profits in updating their equipment multiple times per year. This is backed up by reports from the market (Bradbury, 2014), however, no audited public records exist.

For the purposes of this order of magnitude comparative study, I will assume that the industry is close to efficient, and average network energy efficiency is a sensible weighted average of the best ASIC units currently available, and have been available for a relatively long period of time.

This assumption will also cover the impact of producing the ASICs, as several studies show that the gross majority of impact made by electronics happens during their use, and not during production. Also, 98% of electronic waste is completely recyclable (MRI, 2014).

Social Costs of Bitcoin

Transactional Fraud

Because Bitcoin is resistant to transactional fraud and can be traced through its public ledger, there are no adverse social externalities or costs arising directly or indirectly from Bitcoin mining. Even though Bitcoin addresses are pseudonymous, a good team of detectives will be able to catch a criminal who has not been professionally meticulous in concealing their steps, which is very difficult to do on a public ledger. The slightest lapse of care will make anyone easily identifiable to authorities, and criminal detection rates will be much higher than the 1% success rate enjoyed by authorities in recovering laundered fiat money (UN Office on Drugs and Crime, 2008).

Institutional Fraud / Theft

As is the case with any business or industry where money is involved, especially unregulated industries, there is a large scope for scam institutions and fraudsters. There is also potential for institutional incompetence which makes the job of thieves much easier. To that end, there has been quite a bit of negative media surrounding the extent of institutional fraud and theft in the bitcoin world, with one event in particular, The Mt Gox fiasco of February 2014, being amongst the largest financial loss events in history, resulting in a financial loss of $410 million (Forbes.com, 2014). The below table lists all bitcoin institutional fraud/theft events in history which resulted in a financial loss of more than $50,000 (BitcoinTalk, 2014).

Event	Date	BTC Lost	Equivalent $USD Lost
Mt Gox Collapse	2013-2014	650,000	$410,000,000
Bitcoin Savings & Trust (Ponzi Scheme)	2011-2012	263,024	$2,983,473
MyBitcoin Theft	July 2011	78,739	$1,072,570
Allinvain Theft	June 2011	25,000	$445,688
July 2012 Bitcoinica Theft	July 2012	40,000	$315,133
Linode Hacks	March 2012	46,653	$223,278
May 2012 Bitcoinica Hack	May 2012	38,527	$191,638
“Tony” Silk Road Scam	April 2012	30,000	$146,944
Mass MyBitcoin Thefts	June 2011	4,019	$71,656

Table 23 - List of all Bitcoin theft/fraud events larger than USD$50,000

Comparative Summary

Comparison of Economic Costs

	Gross Yearly Cost
Gold Mining	USD$105 billion
Gold Recycling	USD$40 billion
Paper Currency & Minting	USD$28 billion
Banking System	USD$1870 billion (of which $63.8 billion are electricity costs)
Bitcoin Mining	USD$0.375 billion

Comparison of Environmental Costs

	Energy Used (GJ)	Tonnes CO_2 Produced	Emission Trend
Gold Mining	475 million	54 million	Increasing
Gold Recycling	25 million	4 million	Decreasing
Paper Currency & Minting	39.6 million	6.7 million	Increasing
Banking System	2340 million	390 million	Increasing
Bitcoin Mining	3.97 million	0.66 million	Decreasing

It should be noted that the only thing involved in Bitcoin mining is electricity use, and as the world moves towards clean and renewable energy, Bitcoin will have even less of an impact on the environment (*See Koomey's and Moore's Laws*). There is also much larger scope for energy efficiency improvements in integrated circuits and computing than there are in gold recycling.

Comparison of Socioeconomic Costs

	Gold	Fiat Currency	Bitcoin
Worker Deaths	Over 50,000 historically recorded & Over 100 per year	0	0
Corruption	USD$600m	USD$1.60 trillion	Negligible
Money Laundering		USD$2.65 trillion	
Black Markets		USD$1.80 trillion	
Institutional Fraud / Theft	USD$21 billion across two single events & several billion historically recorded	USD$3800 billion/year & several trillion historically recorded	< USD$0.5 billion ever recorded
Transactional Fraud	N/A	$190 billion	$0
Inflation	Deflationary (Long-term)	3.9% per year (*time to 50% loss of value: 17.5 years*)	Deflationary (Long-term)

Conclusion

As can be conclusively seen, the relative impact of the Bitcoin network does not even register on the radar of the fiat and gold-based monetary systems, representing a very conservative relative environmental impact of just over 0.13%, and a relative economic impact of just under 0.04%. When one considers Koomey's Law, we can expect energy/GH to continue to half every 18 months until 2048. This means that we can expect our current industry best efficiency of 0.408 W/GH to reach 0.0000000873804 W/GH – so critics should note that in the event that Bitcoin scales to a million times its current size and market cap over the next 30 years, its environmental impact will still be insignificant compared to existing systems. When considering Moore's Law, we can expect $/GH to continue to half every 18 months until at least 2020. When we consider the advent of decentralised emission-free renewable energy, we can expect tCO_2/GH, and possibly even $/kWh, to tend towards zero. The more agile and dynamic bitcoin companies can take advantage of these trends, but the sluggish, inert and over-encumbered incumbents simply cannot. As time goes on, Bitcoin only becomes more sustainable, while legacy systems continue to bloat year-on-year.

There are no negative social externalities as a result of Bitcoin proliferation, and any money laundering and shadow economy dealings that currently happen on the network will reduce drastically in proportion as adoption grows and regulations firm up on the on-and-off ramps into the Bitcoin economy. Rome wasn't built in a day, and the crypto-currency space will take time to evolve to ensure that the issues faced and created by our legacy monetary systems do not continue to plague us for the next century and beyond. It has been demonstrated that institutional fraud is a problem systemic to humans, and not to monetary systems. However, transactional fraud is only a problem in legacy systems due to the infallibility of the fact that 2 + 2 will always equal 4.

Although this paper has shied away from all of the ideological and philosophical debates surrounding Bitcoin, what is clear is that the argument that Bitcoin is superior monetary system – from the benefits and protections it provides to merchants and consumers, to the relative lack of negative impact it has on our planet and humanity in general – is a strong one.

The world is currently crippled by several issues, and the human race faces several existential threats such as climate change, the global ageing population demographic crisis and wealth and income inequality. It is also unacceptable in 2014 to still have tens of millions of people forced into labour, and current monetary systems are somewhat responsible for several of the social ills brought about by corruption, money laundering and the black market.

For those who are willing to back their principles and morals with their money, Bitcoin provides the opportunity for socially, environmentally and economically conscious global citizens to choose to no longer participate in the fragile and rotten legacy monetary system, and voluntarily participate in the open and wondrous Bitcoin ecosystem. Due to the several benefits and significantly reduced burden on our planet and society, there is a certain feeling of inevitability about digital currencies, whether it be Bitcoin, or a future currency that proves to be even more sustainable and beneficial for humanity.

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