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Review of the Energy and Social Impact of Bitcoin Mining and Transactions and Its Potential Use as a Productive Use of Energy (PUE) to Aid Equitable Investment in Solar Micro and Mini Grids Worldwide

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I. Abstract

Despite the climate commitments made by countries in the Paris Climate Agreement adopted in 2015, and reinforced during COP 21, world carbon emissions have increased in both 2021 and 2022. It is increasingly unlikely that the world can achieve the targeted 50% carbon reduction by 2030; the reduction approximately needed for reducing global temperature rise since the beginning of the industrial revolution to less than 1.5 deg. C. At the same time, the carbon intensive loads associated with bitcoin mining have grown, thereby contributing to growing worldwide carbon emissions. In this context, the role of cryptocurrency and particularly bitcoin is reviewed from energy and social perspectives. Revealed is the value of a truly neutral and secure currency to much of the world. Also revealed is a growing trend toward powering cryptocurrency miners with renewable energy. In this context, an opportunity for leveraging cryptocurrency, and particularly bitcoin, to fuel investment in solar micro- and mini grids. A number of cases are posed to demonstrate this potential throughout the world and at multiple scales.These include: i). existing microgrids with significant stranded energy to generate income which could be used to reduce the cost per kWh for the community; ii). new solar microgrids optimized to meet community load and mining operations; (iii) solar microgrid powered water purification systems in water scarce communities; (iv) dedicated solar powered bitcoin mining mini grids developed solely to create a funding stream for self-investment of communities for their benefit; and (v) numerous applications where bitcoin mining inclusion in micro- and mini grids can effectively seed microgrid development in places where such investment is not yet feasible. All of these projects are shown to be impact investment worthy.

II. Introduction

The Intergovernmental Panel on Climate Change set as a goal for 2030 50% worldwide carbon reduction as a first step toward limiting global warming to 1.5°C, above which more catastrophic climate change impacts are expected [1]. The Paris Climate Agreement, agreed to by 196 nations in 2015, established a less ambitious plan to limit greenhouse gas emissions to limit global warming to 2.0°C [2]. But, the progress towards even this weak goal is not being made. Global greenhouse gas emissions in 2021 were the highest of all time [3]. The current year (2022) is certain to have even bigger increases, especially as a result of the Russian invasion of Ukraine, which has caused the world to take a step back toward using more coal [4].

In parallel to desires to reduce global greenhouse gas emissions, the United Nations has established goals to achieve sustainability with equity [5]. With over 2B people without access to the economic engine that reliable energy brings [6], there is ample opportunity to integrate equity concerns into potential solutions for the developing world.

Although access to electricity in emerging markets is improving globally, Africa's progress is lagging. According to the 2019 Tracking SDG 7: Energy Progress Report [6], sub-Saharan Africa accounts for 68 percent of the global access deficit, with 573 million people lacking electricity in 2017. By 2030, it is estimated that 90 percent of the global population without access to electricity will be concentrated in the region [6]. Further, there is similar potential to right inequities related to participation by underserved communities in sustainability related initiatives. For example, a 2021 report by the US EPA documents the disproportionately low participation of diverse people in the clean energy workforce and the inequitable energy cost burden on the poor [7]. Likewise a 2020 UN report documents mixed progress in equity worldwide [8]. Group based inequalities are declining in some parts of the world and worsening in others. Income inequality is decreasing between countries but is still greater than inequalities present in individual countries. A recent study by Munoz has highlighted how adoption of renewable energy can exacerbate energy inequality [9].

There are a number of stories that highlight inequities in advancing clean energy in low income communities, wherever they are. In Africa there has been some effort to build solar microgrids in the past few years one village or neighborhood at a time. PowerGen, one of the main developers for such projects, has provided power to more than 50,000 Africans who previously lacked electricity [10]. As of 2021, microgrid projects in India, Indonesia have brought power to over 100,000 people in recent years [11]. Further, the World Bank sees great potential for mini-grids in Africa [12].

But the micro-grids bringing power to people realizing the benefits for power for the first time has required what recipient communities to pay what people in the developed world would consider exorbitant energy costs ranging from \$1.00 - \$1.50 US per kWh [13]. The same report documented lower LCOE's for solar/battery/diesel microgrids, ranging from \$0.785 - \$0.85/kWh. A more recent 2020 pricing for mini-grids noted typical minigrid costs of \$0.49/kWh [14]. Despite these high prices, people receiving the power are paying for it [15].

But, there's a better way. A 2018 report by USAID-NREL emphasized the importance of adding value to micro grids in order to provide affordable power to people new to power. The linkage of a micro-grid to business and industry is termed Productive Use of Energy (PUE). They noted that because of the typically low energy usage of residential customers new to power, micro-grids struggle to reach the critical revenue needed for financial viability. [16]. For example, this study demonstrated the value of increasing the loading on the grid on energy cost.

As well, a 2021 study developed by Power Renewable Energy Opportunities (PREO) provides some tangible benefits for PUE in Sub-Saharan Africa [17]. One example included in this report documents that power directed toward food refrigeration has a sizable impact on small scale farmers; reducing food waste by about a third and increasing farmer income by 20% or more. Even more important, this report detailed that 1.2 trillion is required over the next 10 years to ensure the necessary level of productive, revenue generating demand is created to improve the economics of off-grid renewable energy [18].

Power Africa has sought to broaden the scale of these types of micro-grids. This organization aims to bring first time power to 66 million people in Sub-Saharan Africa, leveraging PUE [19]. They have developed a productive use of energy toolbox that includes 10 country specific catalogs of PUE [20], all of which aim to strengthen local economies. Included in the portfolio of productive investments are agro-processing solutions, cooling solutions (primarily for food), food dryers, livestock and aquaculture, pumping solutions for clean water, and solar sprayers for agricultural use. Local economic assets are part of their solutions. These include agro-processing solutions, cooling solutions (primarily for food), food dryers, livestock and aquaculture, pumping solutions for clean water, and solar sprayers for agricultural use. This effort is a step forward, but it still isn't wonderfully scalable. A brochure is not a design. Every community will be a little different and up-front engineering and design is needed to move a project forward.

Even more importantly, however, is the question about how to actualize investment in PUEs.

There are no easy answers to this question. A 2019 NREL study documented the difficulty in lining up funding for microgrids targeting the 1.1B people (at that time) who lived primarily in rural communities. [13]. This report suggested value from 'bundling' for these types of projects - both operationally and financially; e.g., reliance upon common designs and processes that can be replicated for any site can render efficiencies of scale that bring costs down. Operational bundling is when similar projects are combined in a portfolio in a way that reduces development and operating costs. Included in operational bundling are common designs and engineering easing the pathways for acquiring equipment and contracts, installation and commissioning processes to decrease variability in performance, operational and maintenance processes to reduce variability relative to O&M cost, standardized contracting to reduce variability relative to costs and performance, Productive Use of Energy (PUE) portfolio of assets to enable communities to include similar economic assets in microgrids, and performance monitoring and reporting connecting to a common database to enable 'learning' from all projects to improve future ones.

This paper also emphasized the importance of financial bundling, whereby multiple projects are aggregated into a single portfolio and the benefits and risks are blended, yielding greater opportunity for investment. The authors of this report suggest that this bundling could attract more investment because of the increased portfolio size. Financial bundling includes pooled funds for microgrid operations and growth and for the purchase of electrical devices within a micro- or mini-grid to both create a demand for electricity which ideally better correlates load with supply. Crowd-funding could be leveraged for financial bundling.

The World Bank's Energy Sector Management Assistance Program (ESMAP) sees a significant need for power in Sub-Saharan Africa. Investment is the weak link. Almost $220B USD is needed to provide power access to nearly 500 million people. One small step forward toward this needed investment ($500M) was made by the World Bank in partnership with the African Development Bank in the Nigeria Electrification Project [21]. But, this is only a trickle of investment relative to what is needed.

Another step forward that has brought financial bundling was put forward by Cross Boundary Energy Finance in 2020. They proposed a model where post-construction the micro- or mini-grid asset is purchased by a single Asset Company. This Asset Company owns many such micro- or mini-grids and in effect balances benefit and risk [22]. The revenues, risks, and costs are uniform with this strategy, which also employs a long contract period. This strategy also aligns with the pooled funding strategy previously mentioned.

Additionally, Sun Exchange has developed and implemented an interesting strategy for investment in solar microgrids. They leverage what they refer to as 'earning with a purpose'. It utilizes electronic outreach to crowd-source funding in solar projects for schools, businesses, and other organizations. Sun Exchange provides solar engineering support services to ensure economic and technical viability, as well as social and environmental responsibility. Investors can come from anywhere in the world. Prospective investors are able to purchase solar cells for specific projects through allocation of funds from their personal 'digital wallet' managed by Sun Exchange. After the necessary up-front investment is attained, local companies are contracted to install the solar microgrid. Then the recipient organizations pay individual investors for the clean energy purchased from the solar cells they own. The payment is delivered to the investor's digital wallet [23].

An alternative bundling and PUE strategy is posited here, reliant upon the rapidly burgeoning cryptocurrency transaction and processing industry - for what we are terming 'impact mining'. The elements of this strategy include:

- A common PUE that adds economic value to micro- and mini-grids through off-grid, 100% renewably powered cryptocurrency mining, particularly bitcoin mining;
- A digital energy financial transaction technology where power use at community and individual energy user levels is monitored and measured, aggregated over discrete periods of time (hourly, daily, weekly, etc…) and where payment from energy user to energy provider(s) / investors can be made automatically using the bitcoin lightning network; leveraging either local currency or bitcoin as the transaction currency start and endpoints;
- An automated and smart contracting vehicle that enables investment from one or thousands of crowd funders (termed 'impact miners' here) to a specific project, with terms agreeable to all parties;

- A common database archiving individual project performance relative to cost, power produced, and bitcoin generated from mining, with machine learning-based data analytics to enable improvement in the project design, smart contracting logic, and digital energy to finance transactions.

In this context, the aim of this paper is to present a well-grounded framework for 'impact mining' and its potential for 'impact mining', e.g., attaching off-grid, 100% renewable energy powered, bitcoin mining rigs to renewable energy micro- and mini-grid projects for a variety of different applications and places. Also this paper seeks to show the worldwide potential for this initiative in terms of seeding renewable energy projects at any scale.

III. Background

The introduction section emphasized both the difficulty in gaining investment in micro-grids specifically and underserved/underbanked communities more generally. It also emphasized Productive Use of Energy as a means to improve investment worthiness of projects and guarantee that energy access improves the local economies of the communities gaining access to power. Third, it emphasized the value of 'bundling' relative to micro-grid design, financing, procurement, and installation.

This section provides background on digital currency as an integral component to each of these. To set the stage for what is considered here, a brief background on bitcoin, with pros and cons associated with its adoption, on the mining aspect of bitcoin, likewise with pros and cons established, and on financial transactions.

A. Bitcoin basics

Bitcoin is a form of decentralized cryptocurrency, reliant on a peer-to-peer network called the blockchain to record transactions. It is not tied to any regulatory authority [24]. Blockchain is associated with what are called hash functions which provide a unique record of and authenticate every financial transaction. When each transaction is verified as unique, it is sent to join a "block" of other transitions. At this stage, it becomes impossible to modify. Blockchain represents the assemblage of these blocks.

Blockchain uses many voluntary computer servers to validate Bitcoin network transactions based upon cryptography. The transactions are said to be irreversible. They cannot be undone or changed [25].

All Bitcoin transactions are documented and public, even though the people involved in processing the transactions are anonymous. It is virtually impossible to hack the system, unlike the data breaches which have increasingly been seen with traditional financial transaction companies [25]. When bitcoin is bought, sold, or transacted, no personal information (passwords, credit card numbers, addresses, etc…) are transmitted. There's no personal information to access [25].

In this Bitcoin network, each computer/server performing hashes is referred to as a node. This network now includes over 100,000 nodes worldwide, providing robustness to the overall system. If one of the servers or nodes fails, the rest can perform the necessary functions [25]. This also means that hacking is impossible. A person interested in hacking the system for information, does not know which node or nodes will be called upon for specific hashes. Such knowledge is necessary to steal information, were in fact, any information available [25].

The security of Bitcoin has been proven far more than all other types of cryptocurrency. Further, Bitcoin is more accessible, with more exchanges, more merchants, more software and more hardware that support it. Plus it is integrally connected to energy use. As a result the data security of Bitcoin is exceptional. Other cryptocurrencies are not tied to hardware processing (and thus energy use) and are generally deemed less secure than bitcoin. It is for this reason that bitcoin has continued to be the dominant cryptocurrency in the world.

Bitcoin has been suggested to be an equalizing economic force for the world for a variety of reasons. Upon its inception just after the global economic recession in 2008, it was hailed as “offering a vision of money free from central bank and intermediaries’ control.” The place of the dollar and yuen as currencies of exchange worldwide preference the monetary policies of respectively the US and China. Secondly, Bitcoin is open to everyone [25]. This absence of ownership of currency is especially important for developing countries, where many borrowers borrow heavily using US currency even with non-US lenders. Borrowing in dollars provides access to larger and more liquid global credit markets and helps to de-risk loans. Unexpected fluctuations in local-currency exchange rates can dramatically impact loan agreements from both a lender and borrower perspective. That so much debt worldwide is in terms of US dollars makes the US s Fed policy more powerful internationally than it would otherwise be. A Bitcoin currency in contrast will not, at least theoretically, provide privilege to the nation on top of the financial hierarchy.

But the idea of being a neutral currency has now come into question as a result of the Russian war on Ukraine. Crypto exchange Coinbase in March 2022, blocked transactions from tens of thousands of Russia-linked addresses that it believed were linked to illicit activity to comply with sanctions against Russia. Additionally, Binance, the world’s biggest crypto exchange, has identified and blocked at least one cryptocurrency wallet linked to a sanctioned Russian Oligarch [26].

Others have suggested that bitcoin and other cryptocurrencies can be a more direct asset to the poor. The total amount of money crossing country boundaries is ‘taxed’ considerably by banks for the service of transferring money. This tax is called a remittance. According to a report by the World Bank, around $630 billion worth of remittances are paid each year by the world. This report also documented that prices for sending remittances were over 16% [27]. This is why the U.N. Sustainable Development Goals has set a target of reducing to under 3 percent of the total cost of sending remittances by 2030 [6].

Access to capital for small to medium sized businesses in economically underdeveloped countries and within economically challenged communities in the developed world is a major challenge. For example, the Small to Medium Finance Forum estimates the unmet financing need in developing countries to be $5T. Even when loans are accessible, and lenders meet all credit requirements, small business loans often have interest rates greater than 20 percent [28]. Digital finance (DeFi) enables anyone anywhere in the world to provide and receive loans; often leveraging smart contracts with terms that are automatically executed without the requirement of an intermediary. DeFi has led to lower interest rates [29].

DeFi is especially exciting for providing 'unbanked' people access to capital. Worldwide the number of such people is estimated to exceed over 1.7 billion adults. The World Bank and other organizations interested in mitigating poverty, have long advocated financial inclusion as a pillar of economic development. DeFi offers a scalable solution that circumvents banks. Instead, internet access and a phone can connect people to a suite of extremely low-cost financial services, including savings and spending accounts [30].

Cryptocurrency has also been seen to be a force for freedom. People living under authoritative governments or in the midst of hyperinflation can leverage the 'freedom' afforded by a currency not controlled by the government. For example, the Venezualan government extracts a remittance for all income coming in from abroad.. A wire transfer from the United States can now encounter a fee as high as 56% as it passes from dollars to bolivares in a process that can last several weeks. People can circumvent these fees completely through use of bitcoin [31].

Beyond just lower transaction fees and easier loan repayments, technology supporting DeFi can simplify the process for making loans and donations. Individual donors can specify conditions (the "Directed" part) attached to their donation or investment ("Cash"). Technology can then automatically match donor to recipient (charities, social entrepreneurs) . Furthermore, these "Directed Cash flows" promote accountability and transparency: after receipt, a validation flows backwards to return to the donor so that the donor receives a report of how their donation was spent [32].

But, there are some negative aspects of bitcoin. One, it has been used to launder money [33]. However, the blockchain record has been and is a gigantic obstacle to money laundering [34].

Second, and easily the biggest problem, however, is associated with wild fluctuations in the value of Bitcoin due to the fact that many have seen it as a speculative investment, which particularly in the early years of Bitcoin grew incredibly fast in value. This speculative environment diminishes the value of Bitcoin as a transaction currency. People living in countries with unstable currencies often move their cash to more stable currencies. While high volatility can be an asset for investment, it is not an asset to exchange, where consumers want to be sure that they don't incur losses due to transitory currency fluctuations [35].

A recent study looked at the volatility of cryptocurrencies during the Coronavirus pandemic. instability and irregularity than stock market assets. Examined were 45 cryptocurrencies and 16 stock markets. Their analysis found significantly higher instability and irregularity in cryptocurrencies [36].

This volatility is especially problematic for the poor. Howson and de Vries suggest that because of the volatility, poor and vulnerable communities are disproportionately affected. As well, there are other actors who have taken advantage of economic instabilities, weak regulations, and access to cheap energy to mine bitcoin, often impacting local access to energy [37]. Also, some see the benefit of what bitcoin offers - namely the creation of a permanent untaintable record of a transaction, as a form of surveillance capitalism [38].

Last of all, on the negative side, Bitcoin requires a huge amount of hash calculations to make the peer to peer financial transactions. Each bitcoin miner generates as much heat as a portable heater, this means they will have more power expenditures to cool down the machines [39]. Today the amount of energy being used to power Bitcoin is 138 terawatt-hours of electricity annually — more than the entire country of Argentina, with a population 45 million [40].

But, there have been some improvements. The Bitcoin Mining Council reported that for Q1 in 2022, bitcoin mining energy consumption was reduced by 25%, with 58.4% of the total energy consumption coming from sustainable sources; an increase of 59% from the prior year [41]. In this vein, miners are now investing in renewable energy microgrids to wholly support mining operations. For example, Orcutt describes the development of a 1400 MW wind farm in West Texas, USA, where the wind resource leads to a high wind farm capacity factor, optimized to provide power exclusively to miners [42]. Likewise, Hirtenstein describes a 900 MW wholly wind powered Bitcoin mining facility [43].

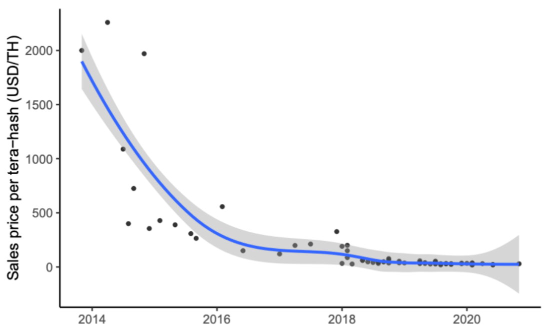
Still others see the technology behind bitcoin as an enabling force to fight climate change. The 'distributed ledger technologies' (DLT) are noted as being capable of providing transparent accounting of energy and carbon use. With this technology, a digital token is envisioned to commercially incentivize and finance a global decarbonised economy to ensure that polluters, rather than governments, fund carbon reduction [44].

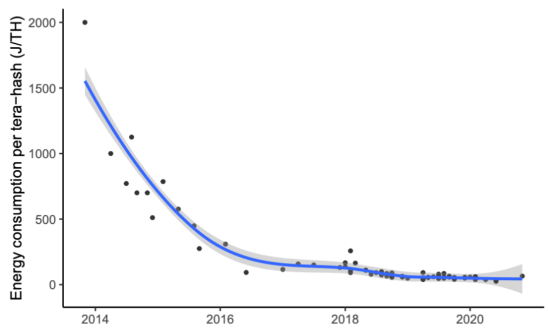
Square's establishment of the Bitcoin Clean Energy Initiative (BTCEI) goes even further. It espouses the opportunity presented by mining to accelerate the worldwide transition to renewables by serving as a complementary technology for clean energy production and storage. While solar and wind energy are now the least expensive energy sources worldwide, both suffer from intermittency. BTCEI sees miners as a flexible load option that could potentially help solve much of these intermittency and congestion problems, allowing grids to experience deeper renewable energy penetration [45].

B. Bitcoin mining profitability

So what does 138 TerraWatt Hours per year for worldwide bitcoin mining translate to in terms of the economic value that can be derived from mining of bitcoin? This annual energy demand is associated with a worldwide power requirement of 15.7 GW. This much power translates to a worldwide bitcoin hash rate of 200 EH/s. At current BTC pricing, this translates to about $9B/year in total income assuming 0 energy cost. At 0.05/kWh, the total income earned is $6.07B/year. At $0.10/kWh the annual total income earned is just over $3B.

But the income earned per hash has been on the decline, as shown in Figure 1a below. Clear is that the mining profitability per hash has declined significantly since 2015, but remained fairly steady since 2019, that is, until recently. At the same time, the energy efficiency of mining has improved considerably over the same time period as shown in Figure 2. The latest and greatest miner, the Antminer S19 xp Hydro has a documented energy efficiency of 27,000 MH/Joules. Thus, while the profitability of mining per hash has declined, the energy use per hash has declined even more. Thus, the cost to mine, assuming little change in energy cost over this time, is about $4x10^{-7}$ what it was at the beginning. Mining profitability is, until very recently, perhaps as strong as it ever has been.





(a). USD/TH

(b). J/TH

Figure 1. Energy demand and sales price per tera-hash. This figure plots the evolution of ASICs in terms of energy efficiency (a) and sales price (b) per tera-hash computing power (Nov 2013-Jun 2020) [46]

As noted, the recent profitability trend shows greater risk relative to mining profitability over relatively short periods of time. Figure 2 demonstrates this. The reward per Terahash in US dollars is shown in this plot. The reward saw highs on the order of $0.45 US/Th/day and lows on the order of $0.1 US/Th in 2022. This represents a four-fold plus difference between the high and low rewards. Nevertheless, even the low reward rate of $0.1 US/Th/day for the best mining technology in the world - currently the Antminer S19 xp - Hydro (255 Th/) which retails for $19,000 US today, still generates an annual reward of in excess of $9,300 US. The simple payback is just over two years for a mining investment. On the other hand, at a daily reward rate of $0.45 US/Th/day, the annual income generated is over $43,000 US. The simple payback in this case is less than five months.

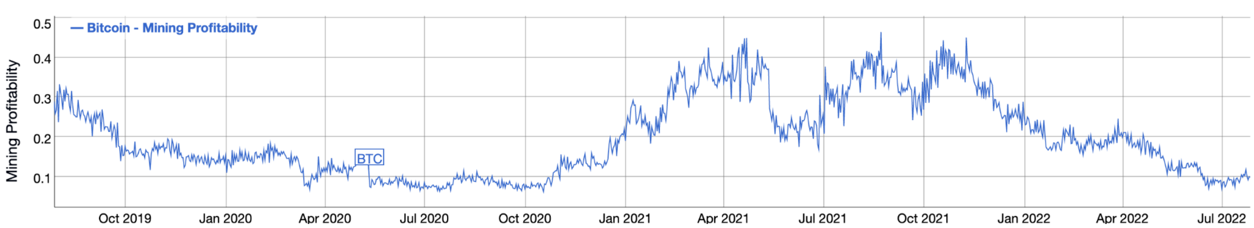


Figure 2. Bitcoin daily profitability ($/Th/day) from the 3rd quarter in 2019 to present day [46]

The future market for mining thus is fairly secure. Minus the massive dip in 2021 when the Chinese government disallowed bitcoin mining in China overnight, one can see a consistent increase in world total hashrate over time (See Figure 3). The development of the Lightning network has been crucial to enabling bitcoin to emerge as a financial transaction vehicle. Fundamentally, this network enables millions of two-party financial exchanges at any time. Moreover, it allows transactions between parties not on the blockchain network. Last of all, like bitcoin itself, this network relies upon blockchains of miners to process transactions. Thus, it offers transparency, permanent documentation, and anonymity.

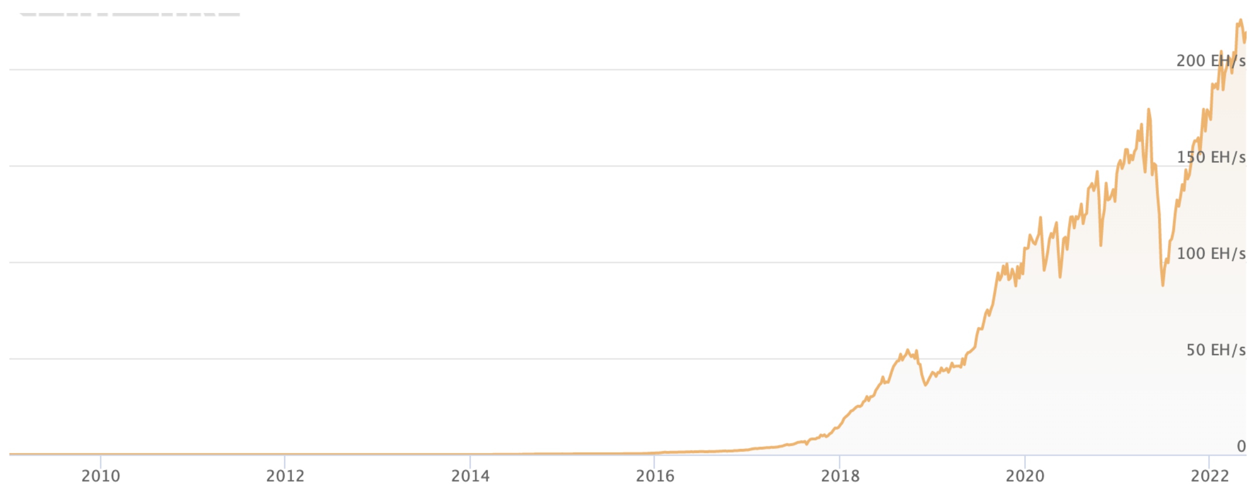


Figure 3. Historical trend of world total hash rate [47]

This network has enabled greater adoption of bitcoin payment transaction pathways. Twitter, Starbucks, Twitch, Whole Foods, Microsoft, Wikipedia, AT&T, Overstock, PayPal, Home Depot, Burger King, KFC, Subway, Pizza Hut, Virgin Galactic, AMC and Twitch are among early adopters of bitcoin as a payment agency. This adoption virtually guarantees greater adoption and thus an increased need for mining.

c. Bitcoin Mining to Seed Renewable Energy Projects

The BTCEI alludes to the possibilities of leveraging mining as a complement to renewable energy microgrids. Recent work by Bastian-Pinto et al. offers a more thorough perspective. They simulated the inclusion of mining into a wind powered micro-grid. The scenario they considered was to optimally switch the generated power from the wind farm to the grid (community members) or to the mining operations depending upon the relative future prices of electricity and Bitcoins. Their results show that the option to switch outputs significantly increases the generator's revenue while simultaneously decreasing the risk of the microgrid [48].

The work presented here, like that of Bastien et al., is premised on the idea of adding mining to a renewable energy microgrid, where the mining is part of the generator’s investment. The mining income, thus, is ‘owned’ by the generator, and as a result increases the investment worthiness of the micro-grid. But, here the focus is on: (1) inclusion of the mining operation in a microgrid in a powerless community in the developing world; and (2) developing mining optimized microgrids at various scales in underserved communities in the developed world to seed microgrids which can, after the investment payback period, be turned over to the community in which the microgrid is premised for power or to continue mining operations to generate a green bank accessible to the community for investment in themselves.

Specific research questions guide this effort.   How does the site and particularly the solar resource impact the economic value that impact mining offers to solar micro- or mini-grid investment and to the communities being served? Also, how sensitive is this value to the bitcoin mining technology employed and to the income derived from bitcoin mining? Third, can impact mining render other social benefits to communities other than the seeding of microgrids to provide power to the community? Can it be an aid to address water and food scarcity in resilient ways? Lastly, can it be used to enable underserved and under-resourced communities to own investment in their own community, both in the short- and long-term?

IV. Method

Power Africa's Productive Use of Energy (PUE) strategy has been demonstrated to have merit in increasing the investment worthiness of solar micro-grids. But, the community economic asset benefiting from the presence of power is dependent upon each specific community.

A productive use of energy strategy for micro and mini grids premised on a common value-add; namely bitcoin mining, is posed. As will be demonstrated, there is enough potential demand for bitcoin mining to seed renewable energy grids to have real impact on communities and villages currently with no or limited access to power. We will also show that this common technology bundling can support investment worthiness for all projects, although with some risk dependent on the income derived from bitcoin mining, and as a result also enable a common investment and payment mechanism.

The following describes the assumptions employed and the generalized model used to predict the value of impact mining, as well as document financial risk. This model posed is inclusive of all of the specific cases considered in the next sections.

1. Assumptions

A number of fundamental assumptions guide the solution posed.

First, the processes already developed by 'on-the-ground' organizations already successful in developing micro-grids are essential. Organizations like Princeton Power Systems], Powerhive, GivEnergy, among many others, know their communities and have already refined the processes to work with local villages and communities to gain buy-in for, develop, and install micro-grids. Organizations like these simply need access to funding.

Second, assumed is that there will be future value in bitcoin mining. The increasing adoption and the increasing amount of transactions based upon bitcoin provides confidence in the future value of mining. Nevertheless, the analysis which follows considers both the high and low rewards from bitcoin mining that was shown in Figure 2 (e.g., $0.1 and $0.45 US/Th/day). Thus the investment worthiness of impact mining for different reward scenarios is considered.

Third, the priority load to meet for the power produced from the micro-grid will be that of the community. Controls to ensure the community needs are met first must be put in place. At the same time, the microgrid will be designed to optimally meet the targeted community demand and the miner demand.

Fourth, power for the mining operation will only come from renewable power sources. This is especially relevant to microgrids added to existing utility grids. Here, we are only seeking solutions without carbon attached to bitcoin operations.

Fifth, the investors own the micro-grid with included mining operations over the investment period, and that the investment is made by impact investors. Thus, the expected interest rate is expected to be anywhere from 0% to 3%. That this is feasible derives from the fact that Bitcoin and cryptocurrency businesses have acquired significant wealth in a short time. There is real benefit to having bitcoin and cryptocurrency be seen as a force of good in terms of cementing Bitcoin as a worldwide currency. Thus there is very strong interest by Bitcoin related businesses to make impact investments.

Lastly, after the investment period (from 3-10 years depending upon the product and the goals for the microgrid), ownership of the micro-grid transitions to the recipient village or community. This means that the community will be able to expand the power available to them to do with as they deem fit. The investment period will then be associated with community development efforts, whereby the community will receive guidance about what they might do with the additional power originally powering the miners.

2. Overview of Digital / Financial Transaction Technology

Proposed here is the use of the Bitcoin lightning network to facilitate decentralized energy payments and settlements to the microgrid / miner investors. This network appears to have emerged in 2015, and matured in concept through 2016 by Poon and Dryja [49]. It has since gained substantial traction as evidenced by the fact that the 2nd white paper has already been cited nearly 1,000 times since then. It was developed in response to the Bitcoin network's inability to process the scale of transactions present in conventional banking systems, effectively making this network inaccessible to the processing of small and frequent transactions.

Today, the lightning network is capable of facilitating extremely fast blockchain payments without worrying about block confirmation times. Security is enforced by blockchain smart-contracts without creating an on-blockchain transaction for individual payments. Payment speed is measured in milliseconds to seconds. As a result, this network is said to be capable of millions to billions of transactions per second across the network. This capacity potential exceeds legacy payment rails by many orders of magnitude. Attaching payment per action/click is now possible without custodians. Further, by transacting and settling off-blockchain, the Lightning Network allows for exceptionally low fees, which allows for emerging use cases such as instant micropayments [49].

In the context of the impact mining scenario considered here; the lightning network enables flow of money from one or thousands of investors for each project and the subsequent energy payments by the recipient community, either in the form of a village level payment or in the form of payments from individuals within a village. The lightning network would negate any cross-country remittances / fees, which average 8.9% for all of Africa [50].

Whatever the case, there would be a low cost Internet of Things energy meter/controller to the microgrid for each energy payee. The meter would almost certainly be set-up for energy pre-pay. Power would be curtailed if community members don't pay for their energy.

Investors would receive village level energy cost payments and income derived from the mining.

3. Generalized Model

A generalized model is posed here. The intent of this general model is to permit testing relative to the questions posed, and ultimately, to enable development of a tool to aid communities or villages to 'design the system' that best meets their needs.

a. Weather modeling

For any site, the local weather conditions are needed in order to estimate the solar irradiation flux needed to estimate and to estimate heat exchange if applicable between cooled spaces and systems with the local environment.

Department of Energy Energy Plus Weather files are available for many worldwide locations [51]. The metadata for the epw files is available from the US Department of Energy [52].

b. Bitcoin mining and Bitcoin mining economics

The model accounts for different BTC mining hardware, from the now nearly obsolete S9 (14 Th/s) device which was unveiled in 2017, to a S19 pro (140 Th/s), to the present state of the art, the S19 xp hydro (255 Th/s). The former has nearly lost any value from bitcoin mining unless the energy cost is close to free and if donated. Here, we are looking at this technology as a potential donation; a feasible assumption because active miners with this equipment are happy to see them emerge for a higher purpose. The mid-range miner, as a result of the recent reduction in mining rewards has seen the purchase price drop immensely, with units now available for nearly $4,000. It may even be possible to acquire these units at substantially lower costs for active miners who have seen the value of these units decline, but who might be excited to see them be used for social impact. Lastly, the high end S19 xp hydro unit presently costs in excess of $19,000.

It would also be possible to include in the model the possibility of over-clocking the miners in order to increase the hash rate; however, such operation can impact the life of a unit. The heat from over-clocking can be compensated for via cooling in immersion oil baths. However, this technology has yet to mature, and thus, here, overclocking is not considered.

c. Community beneficial productive use of energy

This research is driven by the assumption that power is inherently needed by communities having no reliable access to power, and power in itself can help communities power other systems they need to survive and thrive. Ultimately, the model developed here considers the following POU assets:

- Bitcoin mining, where a microgrid investment can render income generation from bitcoin mining
- Container farms, where the microgrid investment can render income from food sales, and
- Water purification systems, where the microgrid investment with bitcoin mining can render income from bitcoin mining and water sales.

These POUs can be considered independently, and can be combined to potentially de-risk projects. Ultimately, however, it depends upon the needs of the community. Where there is food scarcity and climate change impact on food production, the container farm asset is important. Where there is water scarcity along with availability to brackish or salt water, the water purification asset is important.

d. Solar microgrid models

For all of the scenarios considered later, the only differentiators are the size of the microgrid and the type of solar system (fixed or 1-axis tracking). The latter is considered for community-scale solar systems; otherwise fixed tilt systems are considered. In all cases, both solar PV and battery storage are considered. In some other cases, a biomass generator is considered as a potential add-on to the microgrid to account for extended cloudy periods.

In all cases, PVWatts [53] is used to estimate the hourly solar production per each kW of solar capacity, depending upon the type of solar installation assumed. .

e. Demand load modeling

In this work, demand loads need to be established for the various communities and productive use of energy employed.

i. Community load

Here, a number of impact mining scenarios are focused on improving existing microgrids or in establishing new microgrids to meet community load in “new to power” villages in Africa. The per household loads tend to be small and present mostly in the evening. NREL’s rural Africa demand profile is used for this study [54].

ii. Miner load

The miner demand in the models will be constant power as long as there is sufficient supply of power available from solar pv, generator, or batteries.

For now, it is assumed that no additional power, other than what is already present in a miner or miners, is required to cool them. In a future study, this assumption can be relaxed.

iii. Water purification load

Here a single water purification system is considered for one of the cases; capable of producing 6,000 gallons/day (enough for a community of roughly 100 people). The power demand is considered constant as long as there is sufficient power available.

iv. Container farm load modeling

A typical sized mobile container farm is considered (roughly 30 m^2). A container farm manufacturer recommends lighting for 16 hours per day to best stimulate plant growth. For the container farm employed in this study, a lighting power of 4 kW is specified. The envelope of the container farm considered has a thermal resistance of 7 m^2-C/W. The container farm considered relies upon cooling to condense moisture in the exhaust air. Prior research has theoretically both developed a model to estimate power consumption in a container farm and validated the model with experiment [55]. The ventilation requirement is assumed to be 1 air change per hour. The container farm considered relies upon cooling to condense moisture in the exhaust in order to reduce water use. For this air change per hour, the fan power is estimated to be as follows.

$$P_{fan} = 0.6 \times \varrho air$$

where ϱair is the air density (kg/cu.m).

The heat transfer rate through the envelope is assumed at least quasi-steady according to

$$Q_{envelope}(hr) = \Delta T/R$$

where ΔT is the temperature difference between outside and inside, and *R* is the thermal resistance of the envelope, which is assumed to be constant for all walls, ceiling, and floor.

The infiltration heat rate, $Q_{infiltration}$, is equal to:

$$Q_{infiltration} = \dot{m}_{make\ up\ air} \times (h_{out} - h_{in})$$

where $\dot{m}_{make\ up\ air}$ is the make-up air flow rate and *h* is the enthalpy. The subscripts out and in refer to outside and inside conditions. It is assumed that the indoor environment is maintained at $21.1C$ and 60% RH.

Additionally, transpiration from plants adds moisture to the environment. The transpiration rate is assumed to be:

$$\dot{m}_{transpiration} = 2.5kg/h_2o$$

This moisture must be condensed. The rate of energy required to do this is equal to:

$$Q_{transpiration} = \dot{m}_{transpiration} \times (h_{water,vapor} - h_{water,liquid})$$

Lastly, the overall power required is thus as follows.

$$P_{cooling} = \frac{Q_{envelope} + Q_{transpiration} + Q_{transpiration}}{COP_{cooling\ system}} + P_{lighting} + P_{fan}$$

v. Investment modeling

Two options for investment exist. In the first option, the impact miner invests in all of the systems present in a project. These systems include the solar micro- or mini-grid and all of the Productive Use of Energy elements. The intent for this option is for the impact miner investor to couple the economic assets from the PUE elements with the micro-grid in order to improve the investment worthiness of the project.

The second investment option is for the impact miner to invest only in the bitcoin mining equipment, then pay for the energy supplied to the miner. This type of investment option makes sense for existing solar microgrids, where there might be substantial curtailment of the solar resource. For example, in Nigeria, new undergrid mini grids have been developed to accommodate a non-reliable electrical grid system [56]. These 'behind the meter' mini grids are developed to ensure nearly 100% reliable electrical supply. But, curtailment in this type of grid can be in excess of 60%. Bringing in mining operations to utilize this wasted renewable energy is an opportunity to reduce or eliminate this curtailment and generate income that can lower costs to the energy users and improve investment worthiness to the investors of this type of gris. An impact miner would pay a rate of electricity from a low rate, where they can still earn profit, or a rate nearly equal to the mining rewards they earn minus the investment payback for the miners themselves.

4. Optimization Methodology

There are open-source tools to optimize micro-grids. NREL's REopt is most prominent [57]. But, here the addition of miners in the micro-grid, along with capturing both short term and longer term community goals for power requires a different type of optimization pathway. Ultimately this optimization process and tool could be applied to any project anywhere in the world, and to some extent represents a bundled engineering process to help communities and community partners design projects.

The optimization process here follows this pathway:

- Define community goals for power in the short-term and in the long-term (post investment period):
- Define initial community load
- Define miner load needed to improve investment and meet long term community needs
- Define optimization parameter and constraints

· Implement optimization with a genetic algorithm optimization technique.

In all scenarios, a Genetic Algorithm optimization is employed [58]. A population for each generation of 25 is employed. Additionally, in order to enable the solution to reach an optimal condition, 250 generations without improvement in the result is permitted before the optimization is stopped.

V. Case Studies

Table 1 summarizes the context for each of the impact mining scenarios considered here, identifying the community/city/village, their present context, and their short-term power needs, and long-term interests. Interestingly, few of the communities have had the luxury to consider long-term needs. Work is still needed to help many of these communities understand long-term opportunities associated with potential hand-off of the impact mining microgrid or minigrid to the community (and the extra power generation available) after the investment period.

Table 1. Case study context and goals for various scenarios for 'impact mining'

Community/Location	**Current Context**	**Short-Term Power Goals**	**Long-Term Power Goals**
1. Sobongari, Ghana (medium level miners owned by investors added to an existing microgrid to use excess solar)	Village of 100 families (600 people) - w/ recently installed microgrid & detailed cost from RCEI (microgrid contractor/investor) - current microgrid power cost 0.48USD/kWh	- lower cost per kWh for community from using relatively low cost S19 pro 110 th miners to use excess solar only	NA
2. Sobongari, Ghana (medium level miners and battery owned by investors added to an existing microgrid to use excess solar)	Village of 100 families (600 people) - w/ recently installed microgrid & detailed cost from RCEI (microgrid contractor/investor) - current microgrid power cost 0.48USD/kWh	- lower cost per kWh for community from using S19 pro 110 th miners <u>with batteries</u> in order to increase duty cycle of miners to use excess solar only	NA
3. Gbatala, Liberia (new microgrid owned by investor for community power)	Village of 60 families (400 people): - currently no power; food insecurity during rainy season - more than 50% of harvest is lost from pests and spoilage	- lighting for residences and school - refrigerated building for communal storage of harvest	Abundant low cost power as soon as possible
4. Kandahar Province, Afghanistan (new microgrid owned by investor for community power)	Representative village of 100 families (600 people in historically Taliban controlled part of nation)	- cell phone tower - lighting for residences - television - mini-refrigerator	Abundant low cost power

	- occasional and costly diesel power - consistent disruption of diesel fuel - excellent solar resource		
5. Steamboat Chapter, Navajo Nation, USA (solar mining microgrid w/h2o purification owned by investor)	Native American chapter w/ 200 people - fresh water trucked in - 2 gal per day per person - potential water access in contaminated well - food insecure	- Water purification	Same as short term
6. Gbatala, Liberia (solar mining microgrid w/ container farm owned by investor)	Village of 60 families (400 people): - currently no power; food insecurity during rainy season	- Off-grid container farm	Additional investment in indoor farming facilities
7. Saudi Arabia (solar mining microgrid w/ container farm owned by investor)	Food insecurity and lack of food production self-sufficiency is a problem in rural area; strong interest in growing hydroponic indoor farms	- Off-grid container farm	Additional investment in indoor farming facilities
8. Dayton, Ohio, USA (solar mining microgrid w/ container farm owned by investor)	Low-income, primarily black/brown urban neighborhood - food desert - abundance of brownfields - little in terms of outside or city investment	- Off-grid container farm	Additional future investment in indoor farming facilities
9. Dayton, Ohio USA (Solar mining microgrid owned by investor to generate continuous stream of income into a Green Bank)	Low-income, primarily black/brown urban neighborhood - food desert - abundance of brownfields - little in terms of outside or city investment	- Desire to develop community positive systems controlled by community members	Same as short term
10. Dubai (Remote solar mining site owned by investor creating Green Bank income stream)	- Impact mining community can be anywhere in the world - Mining located in Dubai with an exceptional solar resource	- Assured cash flow for organization	Assured cash flow for organization

11. Dayton, Ohio, USA (Home weatherization program, investment from HWAP program)	Low income residences eligible for Federal Home Weatherization Assistance Program (HWAP) investment	- Some energy cost reduction to reduce energy cost burden for poor residents	Assured substantially lower energy costs for (residences)

The case studies posed seek to evaluate the potential for the following type of investments: i). Impact mining in existing microgrids utilizing excess solar power (Cases 1 and 2); ii). Impact mining in new micro-grids optimized to meet both community load and mining load (Cases 3 and 4); iii). Impact mining to support water purification in water scarce communities (Case 5); iv). Impact mining to support off-grid container farms in food insecure communities(Cases 6-8); v) Impact-mining to seed solar microgrids in low income housing to enhance long term energy affordability (Case 9); And impact mining mini grids to develop a Green Bank for communities to invest in themselves (Cases 10 and 11).

Table 1 summarizes the 'big picture' case scenarios considered here. Included in this table is a description which includes the scenario location and general nature of the project (Column 1), the present energy and social context at the site, e.g., current power situation as well as food and water availability (Column 2), plus the short- and long-term power goals for the community (Columns 3 and 4). The long-term goal is especially important. While impact mining has the potential to increase the investment-worthiness of solar micro- and mini grid projects, the continued presence of impact mining post-investment payback is up to the recipient community, as in general they would be the owners of the micro- or mini grid at this time. They can choose to purchase new high end miners to generate income for their communities, or discontinue the mining entirely, using the now lower cost power originally dedicated to mining for other purposes. These other purposes could include increasing power for community members, dedicating power to new "Productive Use of Energy" technologies and systems, providing a micro- or mini grid running parallel to a likely less robust grid system, and more. The investment period thus will coincide with planning for life in the community post-impact mining.

In general, the scenarios shown in Table 1 were selected because these scenarios: i). represent active potential sites for actual projects with on-the-ground partners; ii). collectively offer differences in terms of the available solar resource (Sub-Saharan Africa, South Asia, Midwest USA, and the Middle East); iii). offer differences in mining technology, with consideration of donated S9 bitcoin miners, medium range and relatively low-cost S19 pro miners, and the current state of the art; namely S19 xp hydro miners; iv). offer consideration of other productive use of energy technologies providing resilience relative to food and water scarcity; and v). offer variation relative to the value derived by the community.

Specifically, the aim of each scenario is articulated as follows. Scenario 1 looks at adding medium range, relatively low-cost bitcoin miners to an existing solar microgrid in a small village in Ghana. The evening dominant power use of this community results in significant curtailment of solar energy production, as the microgrid is over-sized in order to sustain access to power during the so-called rainy season. In this case, an impact miner would pay for use of this power for each kWh consumed by the miner. The income derived from the power sales to the miner would be used to reduce the price of power paid for by the villagers.

Scenario 2 considers the same village as Scenario I, but in this case additional battery storage is included in the investment in order to increase the duty cycle of operation of the miners to respond to excess solar loads.

Scenario 3 is for a similar village in Liberia, currently without access to electricity and with a serious food scarcity problem during the rainy season, where on average more than half of the food grown locally spoils. In this scenario, high end S19 xp hydro miners are considered to help improve the investment worthiness of a solar micro-grid in order to meet primarily lighting loads in the village, along with a cooling load for a new refrigerated food storage building. The short-term power goal for this village is to meet the community loads with affordably priced power. For the long-term, the aim would be to shift use of the power initially supporting mining functions to provide low-cost power for needs defined by the village.

Scenario 4 considers a similar situation to Scenario 3, except in a different location (Afghanistan), where the solar resource is less. The area targeted is representative of an area controlled by the Taliban, where villagers have negligible economic opportunity. Energy is central to creating such opportunities.

Scenario 5 was included to show the potential of impact mining to help communities address even bigger problems than access to power. A New Mexico (US) Native American reservation is the considered site for impact mining in this context. The 'chapter' targeted struggles with access to clean water. The average person in this village uses only 2 gal (7.6 L) daily. There is brackish water available but no means to invest in a water purification system [59]. A solar microgrid with bitcoin miners is employed to improve the investment worthiness of the project. Here the water purification system would be part of the impact mining investment, along with the miners and solar microgrid.

Scenarios 6-8 consider a different parallel productive use of energy - indoor grown food - to provide the local community access to healthy food with resilience and income derived from the food sales. These scenarios are proximated in Sub-Saharan Africa, the Middle East, and the US Midwest, respectively for Scenarios 6-8. The primary aim of analysis in these scenarios is to show that income other than from mining can help to 'de-risk' the investment in bitcoin miners. There are multiple reasons for this inclusion. First, the indoor farm market is growing fairly rapidly. For example, in 2019 indoor farming had a \$112.6 billion market value, which is predicted to grow to \$131.2 billion by 2025 [*60*]. Even more important is the issue of resilience in food production, where the climate crisis is causing havoc on local food production. Avgoustaki and Xydis discussed how indoor vertical farming can improve food security, sustainability, and food safety [61]. Integrating indoor container farms into the impact mining investment helps under-served and under-resourced communities overcome the initial cost barrier associated with the purchase and installation of a container farm [62].

Scenarios 9 and 10 focus on solar mini-grids optimized for bitcoin mining only for two locations (midwest US and the middle east). A long-term impact investment period of 10 years is considered. The income derived from mining every year in part pays for operations and maintenance, as well as loan payback.

Beyond this, the mining creates a cash flow into a Green Bank which can be used and controlled by the recipient communities to invest in themselves. The assumption here for the midwest US community is that the mining operations will be present in the community receiving the Green Bank funding. The community would have ownership of this fund to be able to invest in themselves, something that low income communities have rarely had. The Dubai site was selected to show that an impact mining operation supporting a community anywhere in the world could be located in an ideal solar site elsewhere in the world. For example, an impact mining supported operation supporting the Liberian village considered here could be located in Dubai where the solar resource is incredibly consistent.

Lastly, Scenario 11 showcases yet another socially beneficial example; this time to reduce the energy burden associated with low income residents in the US and elsewhere. The US federal home weatherization program facilitated through the Home Weatherization Assistance Program (HWAP) has typically subsidized energy reducing systems in such residences to reduce the energy burden [63]. If solar could be added to such residences, energy costs could be reduced more. But, energy reduction investment is more effective than investment in solar. Here, donated S9 bitcoin miners and a solar microgrid to power these are added to the residences to generate mining income to payback the investment in solar microgrid/mining operation. After the loan is paid off, the house would 'own' the solar microgrid. As a result, long-term energy burden reduction would be assured.

For each of these scenarios, analysis is completed in order to develop an optimal sizing of the system. The objective function chosen for each scenario depends upon the value derived by the community.

Table 2 shows the optimization parameter, constraints (if any), and the case-specific assumptions for each of the scenarios analyzed. In scenarios 1 and 2, the goal is to insure a best investor for the impact miners, who commit to paying $0.10/kWh (marginal energy cost for impact investment). The hope is that the miners generate enough rewards to make the investmentment palatable. In these cases, since the solar microgrid is already in place, the optimization seeks to determine the ideal number of miners to gain the best investment; and as well to impact most the cost per kWh for community members. This latter objective is most important. The investment isn't worth doing unless it has a positive impact on the villagers. The difference in scenario 2, as noted above, is the possibility of adding battery capacity in order to spread out the excess solar and increase the duty cycle of the bitcoin miners. The impact miners would provide the investment needed in the batteries.

In scenario 3 and 4, the optimization focuses on minimizing the investment return period as measured by the simple payback period. Considered in both scenarios is the addition of biomass generators to deal with extended periods of cloudiness. Also, in both cases, the power cost to the community is designed to be small, $0.10/kWh relative to what they would pay were bitcoin miners not included in the project. Further, the microgrid is expected to meet the community load at least 90% of the time. Thus, power for the community would be prioritized over power for the mining operations.

In scenario 5, the optimization parameter again is the simple payback on investment since investment for a clean water system for a water scarce community does not happen without investment worthiness. The optimization parameters are the solar capacity, kW, the battery capacity, kWh, and the number of miners. Fixed is a water purification system supplying 6,000 gallons of water per day for continuous operation. Permitted here on rare cloudy days is a disruption in water flow. As a result, battery storage would not be a priority.   Community members would pay a relatively low cost for water ($0.01/gal) to the impact investor.

In scenarios 6-8, the simple payback is once again the optimization parameter. Fixed is one container farm capable of meeting annual food needs for nearly 100 people. The optimization parameters include solar and battery capacities, and the number of miners. Assumed here is that impact investor owns the miners, solar microgrid, and the container farm. The investment is paid for through both mining rewards and food sales. But the food sales would be market priced in order for the community to be able to afford. Post investment, the community would own the entire system.

In scenarios 9 and 10, the income generated for a Green Bank for the recipient community is to be maximized, given a 10 year return on investment. The impact investors' investment would be paid back through mining rewards alone. After the 10 year investment period, the community would own all systems.

Last of all in scenario 11, the simple payback is again the optimization parameter, as the aim is to enable the solar output to be used by the residence exclusively. The optimization parameters include the solar and battery capacity. This scenario considers a single donated bitcoin miner. Thus, the optimal solar and battery capacity calculated could be scaled if additional miners were added.

Table 2. Optimization parameters and constraints

Community/Location	**Objective Function (OF) / Optimization Parameters (OP)**	**Constraint(s)**	**Case Specific Assumptions**
• Sobongari, Ghana (medium level miners added to an existing microgrid to use excess solar)	***OF***: Simple-payback for investment ***OP***: Number of miners	• Miners use only excess solar production - paying $0.10/kWh US for the power	• All mining income goes back to mining investor
• Sobongari, Ghana (mining+battery for excess solar load)	***OF***: Simple-payback for investment ***OP***: Number of miners, Battery capacity (kWh)	• Miners use only excess solar production - paying $0.10/kWh US for the power	• All mining income goes back to mining investor
• Gbatala, Liberia (new microgrid for community power)	***OF***: Simple payback for investment ***OP***: Solar capacity (kW), Battery capacity (kWh), Biomass generator (kW)	• Meet desired community hourly power load 90% of time	• All mining income during investment return period plus community payments for power ($0.10/kWh) goes to impact investor

• Kandahar Province, Afghanistan (new microgrid for community power)	***OF***: Simple payback for investment ***OP***: Solar capacity (kW), Battery capacity (kWh)	• Meet community hourly power load 90% of time	• All mining income during investment return period plus community payments for power ($0.10/kWh) goes to impact investor
• Steamboat Chapter, Navajo Nation, USA (solar mining microgrid w/h2o purific.)	***OF***: Simple payback for investment ***OP***: # miners, Solar capacity (kW), Battery capacity (kWh)	• Meet water requirements of village	• All mining income during investment return period plus community payments for water ($0.01/gal) goes to impact investor
• Gbatala, Liberia (solar mining microgrid w/ container farm))	***OF***: Simple payback ***OP***: # miners, Solar capacity (kW), Battery capacity (kWh)	• Sing • Meet container farm load 100% of time	• Single fixed size container farm • Variable number of miners
• Saudi Arabia ((solar mining microgrid w/ container farm))	***OF***: Simple payback ***OP***: # miners, Solar capacity (kW), Battery capacity (kWh)	• Meet container farm load 100% of time	• Single container farm • Variable number of miners
• Dayton, Ohio, USA (solar mining microgrid w/ container farm))	***OF***: Simple payback ***OP***: # miners, Solar capacity (kW), Battery capacity (kWh)	• Meet container farm load 100% of time	• Single container farm • Variable number of miners
• Dayton, Ohio USA (Green Bank)	***OF***: Annual cashflow to community ***OP***: # miners, Battery capacity (kWh)	• Meet only miner load • 4 MW solar capacity	• 10 year payback • BTC earnings - loan payback - O&M costs yield annual income for green bank • Cooperative ownership post-investment in a likey era where parallel solar-battery microgrids will be permitted in the US
• Dubai (Green Bank)	***OF***: Annual cashflow to community ***OP***: Number miners, Battery capacity (kWh)	• Meet only miner load • 4 MW solar capacity	• 10 year payback • BTC earnings - loan payback - O&M costs yield annual income for green bank • Cooperative ownership post-investment in a likey era where parallel solar-battery microgrids will be permitted in the US

• Dayton, Ohio, USA (Home weatherization program))	***OF***: Simple payback ***OP***: Solar capacity (kW), Battery capacity (kWh)	• Meet only miner load during investment period	• 5-6 year payback • Afterward miners remove; microgrid system used for house load to reduce energy cost

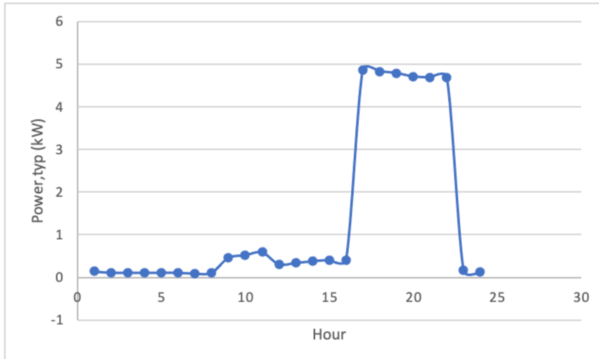
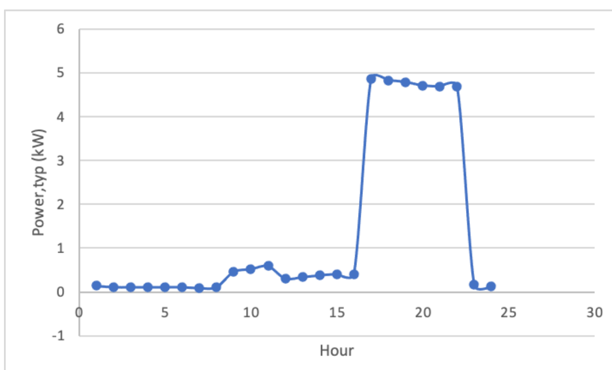
VI. Results

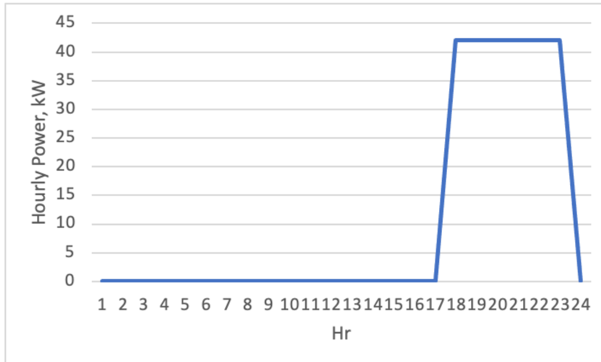
Table 3 documents the pricing and other assumptions employed for the various scenarios. The pricing assumptions included capital costs for the bitcoin mining rigs, solar and battery microgrids, and the income derived from sales (power, food, and water). Typical operation and maintenance costs, while not reported here, are employed, citing references for solar PV and battery systems [64] and bitcoin mining rigs [65]. The loads prescribed to meet community needs, to power container farms, or to power water purification systems are also specified via plots for each of the scenarios where such data is relevant.

Most importantly, in this table, as this study examines the potential for impact mining to improve the investment worthiness for the systems considered in each of the scenarios, a realistic bound on the rewards from mining is set. The maximum bound for the reward is set to the maximum reward for $/Th/day from Figure 2 ($0.45/Th/day). The minimum bound for the reward is set to the minimum reward in the same figure ($0.10/Th/day). It's emphasized that this minimum reward coincides with the lowest bitcoin price for nearly a decade, which strongly impacts mining reward since the mining reward is in terms of bitcoin. Even if the reward in units of bitcoin increases as the difficulty increases (e.g., more hashes happening), if the bitcoin price in USD or other currency is low, the reward is consequently low.

Table 3. Pricing and other assumptions for the scenarios considered

Community/Location	**Cost Assumptions**	
1. Sobongari, Ghana (medium level miners added to an existing microgrid to use excess solar)	• S19 pro 110 Th/s miners; Installed cost, $4,300 US, Shipping cost $100 US For existing microgrid: • Installed cost solar PV, $1,300/kW [64] • Installed cost battery, $400/kWh [64] • Solar capacity, 8.79 kW, 30.1 kWh • Baseline cost/kWh, $0.45 US [54] • Baseline typical hourly community load [54]	• Miner energy pricing paid to community/kWh, $0.10 US • Mining rewards, $0.10 & $0.45 US/Th/day

		
2. Sobongari, Ghana (mining+battery for excess solar load)	Same as above	Same as above
3. Gbatala, Liberia (new microgrid for community power)	● S19 xp hydro 255 Th, cost $19,000; Shipping cost $100 ● Mining rewards, $0.10 & $0.45 US/terrahashes (Th)/day ● Cost per kWh, community, $0.10 US /kWh ● Solar capacity, 8.79 kW, 30.1 kWh ● Baseline cost/kWh, $0.45 US [54] ● Baseline typical hourly community load [54] ● Power cooling for refrigerated building, 0.25 - 0.5kW, daily peak, 5 kW 	● Cost internet $500 ● Installed cost biomass gen, $900/kW ● Efficiency, variable speed gen, 0.42 ● Cost biodiesel per gallon, $3.00
4. Kandahar Province, Afghanistan (new microgrid for community power)	● S19 xp hydro 255 Th, cost $19,000; Shipping cost $100 ● Mining rewards, $0.10 & $0.45 US/Th/day ● Cost per kWh, community, $0.10 US /kWh ● Installed cost solar PV, $1,300/kW [64] ● Installed cost battery, $400/kWh [64]	● Cost desalination system, $17,000 US ● Cost internet system, $500 ● Desalination O&M cost, $700/year
5. Steamboat Chapter, Navajo Nation, USA (solar mining microgrid w/h2o purific.)	● S19 xp hydro 255 Th, cost $19,000; Shipping cost $100 ● Mining rewards, $0.10 & $0.45 US/Th/day ● Cost per gal water, community, $0.01 US /gal ● Desalination capacity, 6,000 gal/day ● Installed cost solar PV, $1,300/kW [64] ● Installed cost battery, $400/kWh [64]	

		
6. Gbatala, Liberia (solar mining microgrid w/ container farm))	● S19 xp hydro 255 Th, cost $19,000; Shipping cost $100 ● Mining rewards, $0.10 (bearish) & $0.45 (bullish) US/Th/day ● Installed cost solar PV, $1,300/kW [64] ● Installed cost battery, $400/kWh [64] ● Container farm hourly power demand, kW (lighting, ventilation, and cooling)	● Cost container farm $140,00 US ● Maintenance cost container farm, $5,000/year ● Income gross, food sales, $73,000/year
7. Saudi Arabia ((solar mining microgrid w/ container farm))	● S19 xp hydro 255 Th, cost $19,000; Shipping cost $100 ● Mining rewards, $0.10 & $0.45 US/Th/day ● Installed cost solar PV, $1,300/kW [64] ● Installed cost battery, $400/kWh [64] ● Container farm hourly power demand, kW (lighting, ventilation, and cooling)	● Cost container farm $140,00 US ● Maintenance cost container farm, $5,000/year ● Income gross, food sales, $73,000/year
8. Dayton, Ohio, USA (solar mining microgrid w/ container farm))	● S19 xp hydro 255 Th, cost $19,000; Shipping cost $100 ● Mining rewards, $0.10 & $0.45 US/Th/day ● Installed cost solar PV, $1,300/kW [64] ● Installed cost battery, $400/kWh [64] ● Container farm hourly power demand, kW (lighting, ventilation, and cooling)	● Cost container farm $140,00 US ● Maintenance cost container farm, $5,000/year ● Income gross, food sales, $73,000/year
9. Dayton, Ohio USA (Green Bank)	● S19 xp hydro 255 Th, cost $19,000; ● Mining rewards, $0.10 & $0.45 US/Th/day ● Installed cost 1-axis tracking solar PV, $900/kW ● Installed cost battery, $200/kWh ● 10 year impact investment return ● Tax incentives, 26% federal for solar system	
10. Dubai (Green Bank)	● S19 xp hydro 255 Th, cost $19,000; Shipping cost $100 ● Mining rewards, $0.10 & $0.45 US/Th/day ● Installed cost 1-axis tracking solar PV, $900/kW ● Installed cost battery, $200/kWh ● 10 year impact investment return	

11. Dayton, Ohio, USA (Home weatherization program)	● S9 xp 14 Th, cost $0 (donated) ● Mining rewards, $0.10 & $0.45 US/Th/day ● Installed cost solar PV, $1300/kW [64] ● Installed cost battery, $200/kWh [64] ● Tax incentives, 26% federal for solar system	● Mining power in the winter reduces heating load

The reality is that mining rewards will decline over time. The block reward for mining has been halved in the past to 25 BTC, then 12.5 BTC, and now to 6.25 BTC . The next halving is expected to occur in 2024. But, the technology used for mining has improved in efficiency and thus lower rewards don't necessarily mean lesser value. Currently, transaction fees make up a small proportion of a miner's revenues, since miners currently mint around 900 BTC (~$39.8 million) a day, but earn between 60 and 100 BTC ($2.6 million to $4.4 million) in transaction fees each day. That means transaction fees currently make up as little as 6.5% of a miner's revenue—but in 2140, this percentage is expected to increase to 100%. It is true that switching to a reward structure based purely on transaction fees would almost certainly decimate the mining network now, since few Bitcoin miners would be able to profitably mine Bitcoin if they received just 6.5% of their typical rewards [66]. However, if the usage of the Bitcoin network were to explode, then competition for block space could increase dramatically. According to ByBit CEO Ben Zhou, that would likely lead to increased transaction fee rewards for miners—similar to what was seen during Bitcoin's 2017 bull run [66].

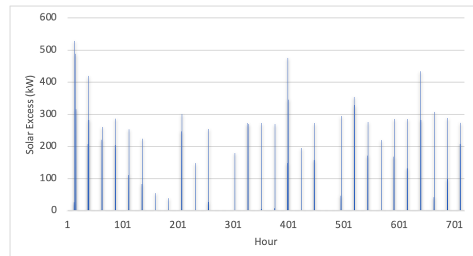
The point is that the long term mining reward in USD is likely to be somewhere between the minimum and maximum bound. With the best mining equipment, or with low to no energy cost, there will always be value from mining.

Table 4 presents the results for each of the scenarios. Included in the optimization are the best values for the parameters defined in Table 2 and the optimal fitness value.

In scenario 1, the addition of a relatively low cost single S19 pro miner to an existing solar microgrid, where the impact miner pays $0.10/kWh for the energy used for mining, yields very little benefit for the community. The income derived from selling the sporadic excess solar production is insufficient to offer any benefit to the community. As a consequence the duty cycle for bitcoin mining, independent of the number of miners used, is very low (0.048). The economic payback for investors, who also want to see social benefit, is nil.

Table 4. Results for cases considered

Community/Location	**Optimal Sizing**	**Optimal Community/Miner Result**

1. Sobongari, Ghana (medium level miners added to an existing microgrid to use excess solar)	● Number miners, 1	● Cost per kWh community, little change ● Simple payback for mining: - Bullish: 6.37 years - Bearish: 80+ years Conclusion: Too great of a risk; Reason - Excess solar is sporadic as evidenced from the figure below.  Figure 1.1. Hourly excess solar production
2. Sobongari, Ghana (mining+battery for excess solar load)	● Number miners, 2 ● Extra battery capacity for mining, 103 kWh	● Cost per kWh, community, $0.243 US/kWh (more than 50% reduction) ● Simple payback for mining: - Bullish: 4.67 years - Bearish: 57 years ● Duty cycle for mining: 0.4 - Bullish: 4.67 years - Bearish: 57 years
3. Gbatala, Liberia (new microgrid for community power)	● Number miners, 5 ● Solar capacity, kW, 12.11 kW ● Battery capacity, kWh, 162 ● Generator capacity, kW, 8.9 kW	● Simple Payback: - Bullish: 1.04 years - Bearish: 4.74 years ● 90.3% of community load met at $0.10 / kWh ● Duty cycle BTC mining, 84%
4. Kandahar Province, Afghanistan (new microgrid for community power)	● 0 miners: Solar capacity, kW - 50, Battery capacity, kWh - 258 ● 2 miners: Solar capacity, kW - 100, Battery capacity, kWh - 385 ● 5 miners, Solar capacity, kW - 173, Battery capacity, kWh - 592 ● 10 miners, Solar capacity, kW - 298, Battery capacity, kWh - 940 ● 20 miners: Solar capacity, kW - 543, Battery capacity, kWh - 1633	● 0 miners: Simple payback, 27.8 years, ● 2 miners: Simple payback bullish- 3.71 years, Simple payback bearish -14.6 years ● 5 miners, Simple payback bullish - 2.7 years, Simple payback bearish -12.2 years ● 10 miners: Simple payback bullish- 2.33 years, Simple payback bearish -11.7 years ● 20 miners: Simple payback bullish, 2.15 years, Simple payback bearish - 11.1 years
5. Steamboat Chapter, Navajo Nation, USA (solar mining microgrid w/h2o purific.)	● Number of miners - 0, Solar capacity - kW, Battery capacity - kWh ● Number of miners = 2, Solar capacity - 55 kWh, Battery capacity - 159kWh	● Solar + battery + desalination system investment will never pay back ● Simple payback bullish - 1.69 years Simple payback bearish - 14.1 years

6. Gbatala, Liberia (solar mining microgrid w/ container farm))	● Number of miners = 0, Solar capacity - 13.9 kW, Battery capacity - 29.7 kWh ● Number of miners = 16, Solar capacity - 532 kWh, Battery capacity - 1240 kWh	● Simple payback - 3.43 years ● Simple payback bullish -3.54 years Simple payback bearish - NA (no payback)
7. Saudi Arabia (solar mining microgrid w/ container farm))	● Number of miners = 0, Solar capacity - 17.89 kW, Battery capacity - 194.6 kWh ● Number of miners = 5, Solar capacity - 101 kWh, Battery capacity - 342 kWh	● 0 miners: Simple payback - 3.43 years ● w/miners: Simple payback bullish -1.79 year, Simple payback bearish - 4.06 years
8. Dayton, Ohio, USA (solar mining microgrid w/ container farm))	● Number of miners = 0, Solar capacity - 13.34 kW, Battery capacity - 21.6 kWh ● Number of miners = 10, Solar capacity - 257 kWh, Battery capacity - 752 kWh	● 0 miners: Simple payback - 2.24 years ● w/miners: Simple payback bullish -1.91 year, Simple payback bearish - 5.78 years
9. Dayton, Ohio USA (Green Bank)	● Number of miners = 300, Battery capacity - 1538 kWh	● Green Investment Fund Income - Bullish - $1.857M/year ● Green Investment Fund Income - Bearish -$0.420M/year
10. Dubai (Green Bank)	● Number of miners = 386, Battery capacity - 2,163 kWh	● Green Investment Fund Income - Bullish: $3.57M/year ● Green Investment Fund Income - Bearish: -$0.219M/year
11. Dayton, Ohio, USA (Home weatherization program))	● Solar capacity, 1.76 kW, Battery capacity - 0 kWh	● Simple payback - Bullish - 3.56 years ● Simple payback - Bearish - 12.5 years

In Scenario 2, additional battery storage is included in the impact mining investment to effectively spread out the excess solar production to enable higher mining duty cycles. At the same time, a higher mining duty cycle means that there are more energy payments made to the community for the mining energy used. This income is considered to reduce the cost of power for community members which is exactly what happens here. The optimal condition is associated with use of 2 medium end S19 pro miners and the addition of 103 kWh of battery storage. The simple payback for investment for bullish and bearish scenarios for mining are respectively 4.67 and 57 years; quite a difference. Both are associated with a mining duty cycle of 0.4 and payments made to the community for mining power of $0.10/kWh. The income received by the community for mining energy use has a gigantic effect on the energy affordability within the community - reducing the power purchase price from $0.45/kWh to $0.243/kWh. If the payment for mining energy to the community were to be cut in half, the community energy pricing could still be reduced substantially to $0.33/kWh, but the risk to the investor would be lessened. For bullish and bearish mining reward scenarios, the simple payback for this case reduces to 4.1 and 26 years.

In Scenario 3, tested is whether a microgrid optimized for meeting both community and mining load yields less risk for the impact mining investment. The results strongly show how the risk to the investment has been mitigated. First, the community load is shown to be met, but with the community paying $0.10/kWh instead of the $0.45/kWh, were the microgrid to be present without parallel mining operations. A total of 5 miners are considered here. For this case, the bullish and bearish mining simple paybacks are 1.04 and 4.74 years, owing to a mining duty cycle of 84%. The required solar capacity, battery capacity, and biomass generator are respectively 12.1 kW, 162 kWh, and 8.9 kW. Further this scenario relies upon the present state-of-the-art in mining technology. This equipment yields the best investment payback and community result, and it represents roughly a two fold increase in power capacity relative to the baseline grid needed to simply meet the initial community load. Thus, at the end of the investment period, the community will have control of more than two times the size of the microgrid that would have been developed for them without the miners.

Scenario 4 considers the same premise as Scenario 3, with the only difference being a location with a lesser solar resource and a community power load that is nearly all in the evening hours. For this case, the baseline microgrid (without mining) is associated with a solar capacity of 50 kW and a battery capacity of 258 kWh. Assuming a community energy payment of $0.10/kWh, the payback period of 27.8 year represents a non-viable impact investment. The investment results associated with the inclusion of miners is far better. For 2,5,10, and 20 miners, the respective bullish/bearish simple paybacks are respectively 3.71/14.6, 2.7/12.2, 2.33/11.7, and 2.14/11.1 years. The lower solar resource definitely increases the payback period compared to Scenario 3. The bearish payback period is, however, still within the realm of impact investment, especially with a greater number of miners. But, the size of the microgrid increases as the number of miners increases. Two miners effectively doubles the size of the base microgrid. Five miners more than triples it. Twenty miners are associated with 10 times more capacity than the base microgrid.

In Scenario 5, we look to see the potential of impact mining in enabling an off-grid water purification system in a southwestern US Native American reservation. In the baseline case, the microgrid includes the water-purification system, solar PV, and battery storage. This system never pays off. The addition of bitcoin miners, however, makes investment in the water purification system feasible. The bullish/bearish mining ROIs are 1.69/14.1 years. The latter value is marginal from an impact investment perspective. If the cost of water to the community is increased to $0.05/gal (5x), the payback ROIs are just 1.04 and 1.79 years. Thus, it is reasonable to imagine that an impact mining investment could make this project happen.

In Scenarios 6-8, we consider container farms as an inclusion in the impact investment. In each of these scenarios, an income of $70,000 per annum is assumed. At this income generation, the investments pay off on their own, without need for impact miners. In Ghana, Saudi Arabia, and Dayon, OH, US the baseline ROIs are respectively 3.43, 3.43, and 2.2 years. However, the mining operations show some benefit. With mining, the respective bearish/bullish mining ROIs are 3.54/NA, 1.79/4.06, and 1.91/5.7 years. It’s clear that the inclusion of another income generator (food) helps to de-risk the mining. Yet, it’s also clear that the mining in the bullish extreme improves the investment substantially.

Scenarios 9 and 10 seek to show the potential of a mining dedicated solar microgrid from generating a source of income that an under-served and under-resourced community could use in the form of a Green Bank for self-investment. An impact investment framework is employed, where the investment iis recovered over a ten year span. In both cases a 4 MW solar microgrid is assumed. The results are very good. For the US midwest site, a bullish scenario yields an income stream of $1.87 M per year, while in the bearish scenario, there would be a $0.42M per year loss. For the Dubai siting, where the solar resource is much better, the results are better; 3.57M/-0.219M. Certainly the prospect of building impact mining solar mini grids at sites with an optimal solar resource is worth considering. Even the bearish annual loss of -$0.219 may be an acceptable risk, given that the overall investment needed for the 4MW project is $11.7M. Moreover, the payback period could be extended to, say, fifteen years, and even the bearish case yields a positive income stream.

Last of all, in Scenario 11, we see that donated older model miners added to a low income residence can render a simple payback of 3.56 and 12.56 years for bullish and bearish mining scenarios. As well, the resident of the house could derive some savings from the heating that the miners offer during the winter ($70/miner/year). The use of three S9 miners would enable construction of over 5 kW of solar capacity and over $200 US/year in heating cost savings. While the bearish scenario payback may not be adequate, the HWAP program could dedicate some of its funds to help de-risk this aspect of the project..

VIII. US Inflation Reduction Act Impact

One final case is considered demonstrating the potential linkage between policy and impact mini. This case emerged from the passage of the Inflation Reduction Act (IRA) in US in July of 2022. The IRA established more than $135 billion for clean energy tax credits to ramp up solar and wind power in the US. The bill will invest $60 billion in environmental justice to ensure that mostly Black, Latino, Indigenous and low-income communities also benefit from a clean energy future [70]. It specifically creates a 40% investment tax credit for solar or wind projects located in a low-income community and 20% for facilities part of low-income residential housing or low-income economic benefit projects [71]. An investment tax credit of 60% for projects in LMI communities is thus available. There is real opportunity to invest in community solar projects in such communities. However, the potential to get a solar farm approved and tied into the grid within the 2024 window afforded by the IRA is almost impossible. For example, in the US Northeast PJM utility grid system, there is a backlog of projects awaiting approval for grid tie in [72]. Proposals have been waiting a year and often longer for PJM Interconnection. The time lag between project proposal to completion is now on the order of seven years.

An impact solar mining farm, where the solar system would effectively be 'behind the meter' may make immediate sense. This type of installation does not require authorization from the grid manager. Moreover, any excess solar produced from a solar farm powering a mining operation would be able to access the required net metering purchases from the utility provider, which is sold back to the grid at generation rates, which are increasing rapidly. Now, such energy can be sold back to the grid for as much as $0.07-$0.08 USD/kWh.

For this scenario, the following assumptions are made. S19 Exp-Hydro miners are assumed. The annual mining income for 24-7 miner operation is assumed to be associated with the current value ($9,450). The miner cost is assumed to be $9,000; much lower as a result of reduced recent demand. A 5 year miner life is assumed; with reinvestment then in new miners. A 10 year payback period is assumed. The investments in the solar/battery mini grid and the bitcoin miners are depreciated in conventional ways. The solar / battery system depreciation amount is (1-0.5 x Investment Tax Credit). The Bitcoin miner investment can be depreciated at a maximum of $1M USD / year. The solar and battery unit costs of respectively $1.50 USD/W and $1.20/kWh are assumed.

Such a micro-grid MUST have value to the low to moderate income communities. One option would be to utilize this solar impact mining minigrid to generate annual funds for a green bank fund to be managed and owned cooperatively by a community. Community members would have 100% control of the allocation of funding; but the green bank idea would preference investment in things like rooftop residential solar and community indoor or outdoor urban farms. Regardless, an optimal sized system therefore would payback the investment in a reasonable time period (here assumed 10 years) while maximizing the funds put annually into the cooperative green bank.

One case of this scenario was investigated for a midwest US urban setting in a predominantly black and brown neighborhood. A 4 MW solar farm was investigated. Table 5 shows the optimal sizing and economic benefits. It should be noted that locating at an urban location with a more favorable solar budget would certainly yield a greater payback to the community.

Table 5. Optimal size of solar impact mining minigrid and financial benefit

No.Miners	250
Solar.Capacity.MW	4
Battery.Capacity.kWh	3,368
Income.Green.Bank.Annual	$155,000 USD

Post investment payback, the community bank cooperative would ideally be the owners of the solar impacting mining site. It would be their choice as to whether to continue the mining or reorganize as a community solar microgrid. For the scenario considered, after considering operating costs, the site could generate roughly $1.2M/annually for the community through the end of life of the farm.

IX. Conclusions

This study has envisioned the possibility of impact mining to seed solar microgrids in order to impact communities beneficially. It has shown, albeit with some risk based upon the risk associated with rewards earned from bitcoin mining, the potential of inclusion of bitcoin mining operations in solar microgrids in order to improve the investment worthiness, while also benefiting the recipient communities through lower power rates over the life of the microgrid, increased low cost power after investment payback, resilient indoor food production and water purification, reducing the energy cost burden for poorer people, and/or in generating funding for self-investment by underserved and under-resourced communities in the form of a Green Bank. A bullish bitcoin mining rewards consideration makes all such investments almost automatic.A bearish bitcoin mining rewards structure still in general enables an impact investment (longer term investment periods) to achieve community benefits.

There are numerous limitations of the research which must be explored further. For example, mining rewards per hash are certain to decrease with time. Reliance upon a fixed hardware for mining will render lower rewards over the life of an investment. For example, the S9 miner which was introduced in 2017, five years later has retained little value relative to bitcoin mining unless they are a donated asset and unless the energy cost for the mining operation is zero (e.g, the mining income only is used to benefit the recipient community). The reality is that investment periods longer than five years likely will require re-investment in new mining hardware after four or five years, even when purchasing the best available mining hardware at a project's inception.

Secondly, the ability to bring mining to different places in the world is not assured. For example, cryptocurrency transactions are now banned in the Cemac zone (Cameroon, Central African Republic, Congo, Gabon, Equatorial Guinea) in Africa. This decision results from the will of the Cobac to "guarantee financial stability and preserve customer deposits" [67]. The fact is that bitcoin mining rewards generate bitcoin, not local currency. If the impact miner owns the mining asset, and they are located outside of the location where cryptocurrency transactions are not permitted, this isn't a problem. They will be able to collect the rewards and either store them or convert to local currency. However, if the mining asset is owned by an organization within the cryptocurrency banned region, then there a solution is needed to convert earned bitcoin to local currency, and at little cost.

Third, the ability to transport bitcoin miners into different locations worldwide is also not assured. A number of companies have banned or restricted bitcoin mining [68]. But this has occurred because bitcoin mining was riding on the existing grid. Large mining operations couldn't be supported by the local grid system. Even if the miners can be transported into a company, the cost of transport can be exorbitant [69].

Clearly, more work is needed.

But, the potential impact is worth moving forward. In Section II, the total worldwide mining power demand was stated to be in the range of 15.7 GW. What if a small fraction of this power could be used to seed solar microgrids?

The US NREL established a typical load profile for a rural village of 100 households (~450 people) in Sub-Saharan Africa gaining access to power for the first time through a solar microgrid. Assumed is a load profile that meets all household power needs, along with power needs in one school and two small businesses. A daily village level total energy demand of 54 kWh is estimated, translating to an average power demand of 2.25 kW or 0.005 kW/person.

If solar/miner microgrids could be established, where the power allocated mining within a community would be three times the original community demand, the effective mining load per person would be 0.015 kW. If 100% of the mining load worldwide were to be allocated toward mining to seed village microgrids, over 1B people could be given access to power for the first time. Plus in five years, the mining operations could be moved elsewhere. Another 1B people could be impacted.

Utopian. Yes. But unrealistic. Maybe no. Bitcoin advocates want to see this currency emerge as the world currency. They want it to be seen as a force for good.

VIII. Acknowledgement

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