MINING & ENERGY

SPARKING A GREEN REVOLUTION IN MONTSERRAT

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Background

Montserrat is a British Overseas Territory in the Caribbean with a population of ~4,400. The island was home to around 18,000 until the 1990s, when a volcanic eruption devastated the island, forcing the majority of the population to flee as refugees in 1995. The southern half of the island remains uninhabited and is subject to various exclusion zones due to ongoing volcanic activity.

With the help of substantial reconstruction efforts from the UK Government, Caribbean Development Bank and other benefactors, the northern half of the island has slowly recovered.

Abundant Energy

Montserrat has an abundance of renewable energy but lacks the means to exploit it. As recently as 2020, 97% of electricity generation was provided by diesel generators, and together with transport, the island was 99% powered by fossil fuels[1].

Montserrat has recently installed two solar plants with a peak capacity of 1 megawatt (MW)[2], and a battery storage system of 1.1MW-hour (MWh)[3], however the island remains highly reliant on oil, and consumers are hence exposed to volatility in the global oil markets. Domestic electricity is priced at $0.53 per kilowatt-hour (kWh)[4], which is very expensive in global terms and far higher than the Caribbean average.

Volcanic activity on the island means that there is the potential for a steady supply of geothermal energy, and the island has been examining the feasibility of exploiting this, having funded the drilling of three geothermal test wells in recent years via the Foreign and Commonwealth Office. One of these wells has collapsed, but the remaining two produced steady and reliable thermal output[5]. Despite completion of long-term testing and feasibility studies, the geothermal plant has not been built; the capital costs are a significant obstacle for the small nation. Whilst the plant would be a significant public cost saving in the long run, the Government of Montserrat lacks the means to make such a large investment up-front.

Montserrat's average electrical power demand is 1.2MW[6] and the UK government estimated that the two remaining existing geothermal wells could provide 3-4MW of electrical power[1]. A further report by a specialist geothermal consultancy recommended a more conservative estimate of 1.5MW[1] - which would still be greater than the average power demand of the nation.

[1] *Energy Task Force Final Report* (June 2021). Ministry of Communication, Works, Labour & Energy (MCWLE), Government of Montserrat

[2] *Powering Montserrat with Solar Energy* (May 2022). Energy News, Government of Montserrat

[3] *Ground Breaking Ceremony for the Solar PV 750kW Project* (January 2021). Energy News, Government of Montserrat

[4] *Energy Snapshot Montserrat* (Sept 2015). Energy Transition Initiative

[5] *Powering Montserrat with Geothermal Energy* (May 2022). Energy News, Government of Montserrat

[6] *Energy Report Card* (2019). Caribbean Centre for Renewable Energy & Energy Efficiency

Geothermal energy is a proven and reliable technology, with nations such as Iceland, New Zealand and El Salvador deriving significant amounts of their base energy supply from geothermal sources.

There are no fuel costs; capital costs tend to dominate the business case due to the need for expensive drilling operations - but note that these have already been completed and paid for in Montserrat. The island already has an electricity grid, it would merely need to switch the supply from diesel generators to geothermal.

It is clear that geothermal power would be both feasible and highly beneficial for the island, but the realities of funding a large infrastructure project on a small island presents too high a hurdle at present. Unless the UK or another state-level organisation decides to subsidise the construction of the plant, it appears that no realistic way forwards exists.

The Government of Montserrat has already gathered feasibility studies and cost estimates, and at the time of writing, the UK government is assisting in a private tendering exercise for construction of the plant. .

We propose an addition to the energy grid that would provide a significant secondary income stream without competing with consumer demand for electricity - one which uses waste energy and would significantly improve the economics of the geothermal plant, reduce risk and makes investment much more enticing. By providing a guaranteed secondary revenue, it may be possible to secure loans or investments, rather than being constrained to applications for governmental grant funding. This is the missing link in the geothermal project.

Stranded Energy

Montserrat's small population and large geothermal supply is an unusual situation in which the existing geothermal wells, solar and battery power should already be adequate to meet the majority of electricity demand.

Most nations have a variable energy supply that can be throttled up and down to meet demand throughout the day. Generally, this is achieved with fossil fuel powered plants whose output is matched to demand in real time. With a geothermal oversupply, the situation is inverted - renewable output must be cut or intentionally wasted to reduce supply to match demand.

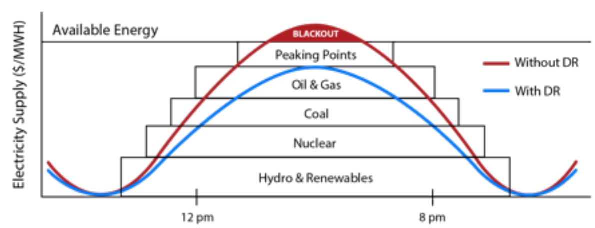

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Figure 1: Typical Hierarchy of Demand/Supply Mix

Gross annual consumption on the island is estimated to be around 12 gigawatt-hour (GWh)[1]. Even the conservative estimate of a 1.5MW geothermal plant would provide 13.1GWh annually. The solar plant is estimated to produce an additional ~1.6GWh[7] with the battery able to shift capacity from the solar supply peak at noon to the evening demand peak. In gross terms, the island would appear to have access to a modest oversupply of renewable energy already - it just needs infrastructure to harness it. However, supply of renewables cannot be easily controlled to match demand from consumers, unlike diesel generators which can be easily throttled up or down according to demand. The picture is more complex than simply matching gross supply with gross demand - daily fluctuations matter.

Demand is much higher during the working day, with a peak around dinner time and gradual reduction to an overnight low. Most large grids with diversified energy sources usually match their base supply (nuclear, geothermal) to the overnight low, with renewables topping up supply during the day, and fossil sources being throttled up to match supply exactly to demand.
Most grids with solar power feature a "duck curve" where non-solar sources may be throttled down as daylight builds and supplies more energy to the grid.


Gretar Ívarsson

A majority supply of geothermal and solar in Montserrat would be a highly unusual case - where the base supply exceeds demand for most of the day, with a brief shortfall around dinner time, where battery discharge and a small amount of diesel generation would be needed.

In such a system, periods of excess energy would simply lead to curtailment of generation - solar panels would be electronically limited, and the geothermal wells would be throttled down, or excess steam vented. Note that there is no cost saving in doing so, since both fuel sources are free and have no meaningful limit. This leads to a problem of stranded energy - there is free electricity with zero marginal cost of production, with nowhere to go.

It should be stressed that this problem is a happy one - the island should be able to switch to cheap and plentiful renewable energy, significantly lowering electricity bills, freeing up citizens' disposable income to be spent in the community instead of sent abroad to pay oil producers. It would vastly reduce the carbon emissions of the nation and enable secondary benefits like cheap electrification of transport.

The "problem" of stranded energy is one of missed opportunity - there are millions of dollars worth of extra energy with nowhere to go. Monetising this stranded energy would significantly improve the business case for the geothermal plant.

Stranded energy is a problem that many developed countries are grappling with. Whilst technologies to shift supply like large-scale battery storage and hydrogen production are promising solutions in large nations, these technologies are in their infancy and Montserrat, as an island nation, has no realistic prospect of export, and little point in adding much more battery storage once daily peaks have been ironed out.

The problem is that the energy is geographically stranded in Montserrat. It cannot realistically be

[7] Ref 1 gives an average generation of 4.4 kWh/kWp/day.

moved beyond the island in the form of electricity - but instead we propose it could be transformed into digital property and moved and sold electronically. The electricity grid does not reach beyond Montserrat, but the internet does.

The Solution

Bitcoin mining is the process of expending energy in high performance computers to solve iterative mathematical problems to find bitcoins - unique items of digital property that cannot be copied or pasted. Many people colloquially refer to Bitcoin as "digital gold", as it can be helpful to understand Bitcoin as a form of property which is finite, scarce, and useful as a form of money, similar to gold.

> "The ability for Bitcoin miners to dynamically flex their power consumption during periods of excess supply and/or low market demand can provide additional incentive to the buildout of additional renewable energy capacity."
>
> *Bitcoin's role in the ESG Imperative (2023). KPMG LLP*

15 years after its launch, Bitcoin is now in the mainstream adoption phase - with the launch of Exchange Traded Funds (ETFs) on the stock market from the world's largest financial institutions like Blackrock, Fidelity and Goldman Sachs. UK pension funds began investing in 2024[8] and there is growing bipartisan support in the US for a Bitcoin strategic reserve[9]. There is large and increasing global demand for anyone that can produce Bitcoin.

Bitcoin mining has been monetising stranded energy worldwide for several years, with numerous successes in radically improving economic and environmental conditions at a national level:

- Deutsche Telekom began mining with stranded renewable energy in Germany[10] in Autumn 2024, very similar to our proposed plans for Montserrat.
- Bhutan has monetised its spare hydro power since 2019, gathering a national treasury of Bitcoins worth around 30% of the nation's entire GDP, allowing it to turn around its indebted economy whilst retaining its enviable status as a carbon-negative nation[11].
- Farmers in Ireland are running methane-powered mining rigs to mine Bitcoin from cow dung, instead of venting methane (a powerful greenhouse gas) to the atmosphere[12].
- Companies in Africa bring electricity to rural communities by building "micro" solar electricity grids, funded by mining with the spare energy [13].

There are many outdated and unhelpful myths around Bitcoin mining - the reality is that the economics of mining mean it is only viable using the very cheapest stranded energy, usually from renewables that would otherwise go to waste. It can be helpful to imagine Bitcoin mines as the "recycling plants" of the energy industry - a vital part of a sustainable integrated energy system.

8 https://cartwrightbenefits.co.uk/news_press_november_2024.html
9 https://cryptobriefing.com/bitcoin-reserve-asset-following-trump/

10 https://finance.yahoo.com/news/german-telecom-giant-deutsche-telekom-082555996.html
11 *Bhutan - Another Country Using Bitcoin To Escape Poverty* (Oct 2024). Bitcoin Magazine, Alex V. Frankenberg
12 *How cow poo is powering crypto mining* (June 2021). BBC News
13 *Bitcoin's role in the ESG Imperative* (2023). KPMG LLP

Indeed, monetising energy that would otherwise be wasted actually improves the profitability of renewables whilst reducing consumer bills - a win-win. In this way, Bitcoin incentivises environmentalism and renewables.

A recent Princeton study showed that Bitcoin mining as a renewable demand-sink had 100-1000x greater value than other competing technologies like hydrogen electrolysis or water desalination[14] - and indeed the heat output from the mine can be further used in industrial or district heating systems.

We propose a small industrial bitcoin mine (~0.5MW, about the size of a shipping container) which would produce millions of dollars of revenue from the renewable energy in Montserrat that would otherwise be totally wasted. This would be a substantial secondary revenue stream that improves the profitability and revenue of the geothermal plant, transforming the idea into a profitable, investable endeavour.

The inclusion of a Bitcoin mine within the island's energy system would enable the funding of the geothermal plant as a commercial business - either through private lending, or a development project funded by the UK Government, Caribbean Development Bank or another interested party.

The UK's FCDO is supporting a live tender from the private sector for the plant, and the Department for Energy and Net Zero, and the Department for the Environment, Food, and Rural Affairs have been providing technical expertise on the matter[15].

Business Case

Assumptions

Projections for Bitcoin mining revenue are relatively easy, as the competitive nature of Bitcoin mining means the marginal cost of production tends towards the marginal product. Historically, the revenue per kWh has varied from $0.08 in March 2020 to $1.65 in December 2017[16]. For the purposes of this paper, conservative figures are used, with a minimum of $0.05 per kWh (often used as a "rule of thumb" for the breakeven energy price for small scale miners), $0.24 as the median from 2015-2023, and $0.59 as a realistic maximum, excluding brief bull-market peaks.

Daily and seasonal variations in demand and solar supply are not modelled. Averages are used; any future assessments would need to perform a sensitivity assessment to determine how weather and seasonal variations would affect the optimal sizing of the system.

Grid resilience measures that may necessitate the off-peak operation of the diesel generators or battery (e.g. frequency response or "peaker

[14] *Understanding the role and design space of demand sinks in low-carbon power systems* (Dec 2024), Sam van der Jagt et al.

[15] *https://questions-statements.parliament.uk/written-questions/detail/2024-09-09/4616*

[16] *Energy Arbitrage: Analyzing Bitcoin Mining's Historical Revenue per kWh* (Feb 2023). Hashrate Index, Jaran Mellerud

plant" operation) are not modelled. The Bitcoin mine would be set up to provide rapid demand-side response to curtail energy use during primary demand peaks, operating like an "inverse" peaker plant.

Diminishing returns from hashrate increases are not modelled - Bitcoin mining rig renewal must be included in any future analysis of operating cost projections. A Net Present Value over an average rig lifespan is given later in this document.

Marginal costs for the geothermal plant and waste energy are assumed to be nil - the offtake of spare energy to a Bitcoin mine should not result in any increased costs. An output of 1.5MW is our primary assumption for the geothermal plant output, as this was within the "reasonable" range recommended by specialist geothermal consultants following long-term tests upon the wells.
A more optimistic output of 3.5MW is also included, based on estimates from an early market engagement survey by the Government of Montserrat[17], it is unclear how feasible this would be in practice.

Demand Model

Real data for hourly consumer demand is not available - instead, a profile was constructed using peak and average demand figures (2.31 and 1.2MW[6] respectively) fitted to a demand curve based roughly upon data available for the nearby Dominican Republic[18]. This method results in a daily gross demand that approximately matches the real demand data.

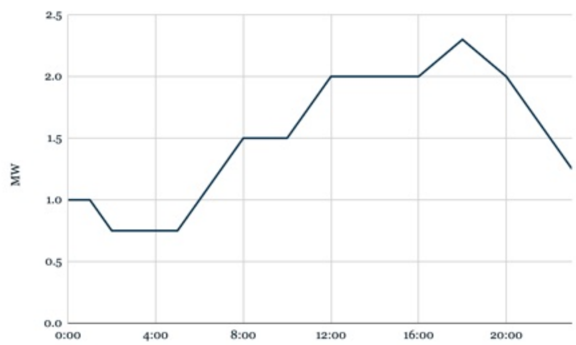

Figure 2: Daily Demand Profile

Energy Supply Model

There are four supply sources in our model:

Solar Photovoltaic (PV) Supply
Supply was modelled using the Government of Montserrat's figure of 4.4kWh of daily generation per kW installed. As a tropical nation, Montserrat enjoys relatively stable daylight hours throughout the year, so a daily profile of PV output was taken from an online tool based on data from Solargis[19].

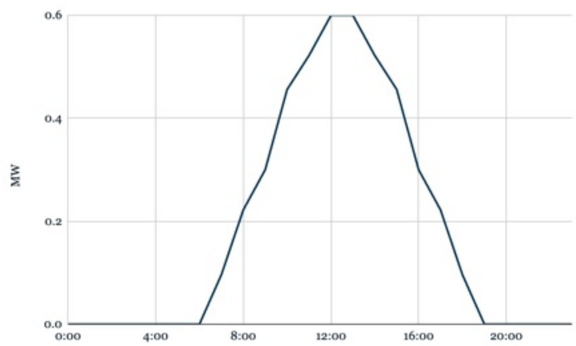

Figure 3: Solar Supply Profile

Geothermal Supply
Geothermal supply was modelled as a constant 1.5MW.

[17] *MONTSERRAT GEOTHERMAL PLANT PUBLIC PRIVATE PARTNERSHIP - Design, Engineering, Procurement, Construction (EPC) and Partial Financing services for Montserrat Geothermal 2.5 – 3.5 MW Plant development* (Nov 2017). Government of Montserrat
[18] *Impact of COVID-19 on electricity demand of Latin America and the Caribbean countries* (Jun 2022), E.F. Sánchez-Úbeda et al

[19] https://globalsolaratlas.info Average hourly profiles for Montserrat

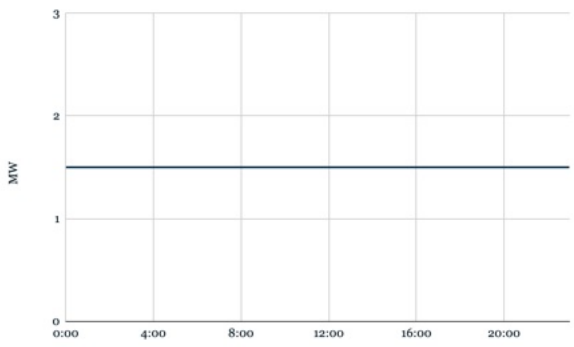

Figure 4: Geothermal Supply Profile

Battery Supply
The existing battery supply is modelled as an energy arbitrage tool - charging overnight during the period of minimum demand, and then discharging during the evening peak. It is assumed that the battery would always be prioritised over Bitcoin mining as a primary demand.

Any "peaker plant" operations of the battery are not modelled here.

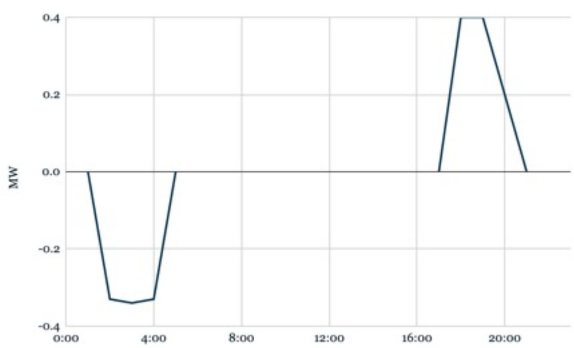

Figure 5: Battery Supply Profile

Diesel Generator Supply
As the island already has the capacity to run on a 100% diesel supply, it is assumed that the existing infrastructure can operate as a "replacement reserve", filling in the daily shortfall in renewable supply around the evening peak. The diesel supply is assumed to switch off completely outside of the evening peak.

Results

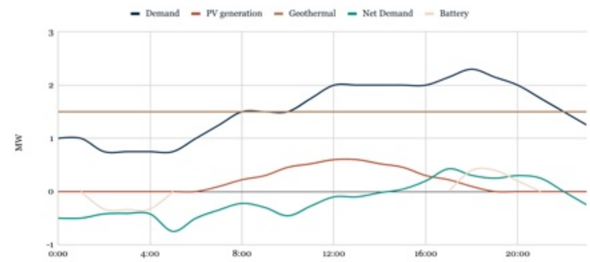

Figure 6: Net Supply/Demand Profile

The model shows a gross daily renewable (solar and geothermal) supply of 40.4MWh and a gross daily demand of 36.6MWh. The island's battery shifts 1MWh of energy from the overnight low to the evening peak. 4.4MWh of daytime solar power plus the steady geothermal supply fulfils the daytime demand.

But this is not the full picture. As supply and demand are not perfectly matched, a net oversupply and undersupply exist which cannot be reconciled:

- There is an evening peak (approx 16:00 to 21:00) that cannot be met by renewable and battery supply - a modest 1.7MWh of replacement reserve diesel power would be required.
- Similarly, there is 5.6MWh of oversupply between 21:00 and 16:00hrs which cannot be consumed by the battery or primary demand - this is stranded energy.

The profile of this stranded energy is a fairly steady ~0.5MW over approx 19 hours - ideally suited for a Bitcoin mine.

Revenue Estimate

By taking the daily stranded energy and applying our low/medium/high assumptions for mining revenue per kWh, we can arrive at a notional annual revenue from a suitably designed Bitcoin mine:

	Mining Revenue Estimate		
	Low	Med	High
$/kWh	$0.05	$0.24	$0.59
Revenue	$101,616	$487,757	$1,199,069

Note that the medium scenario would constitute a direct boost of 0.6% to national GDP[20]. If we use the more optimistic figure of 3.5MW output from the existing geothermal wells, we arrive at the following Bitcoin mining revenues:

	Mining Revenue Estimate - Optimistic		
	Low	Med	High
$/kWh	$0.05	$0.24	$0.59
Revenue	$945,204	$4,536,979	$11,153,407

Costs

Assuming a capacity of 0.5MW, this would correspond with a single 20ft ISO shipping container- type mine. There are various "prefab" designs on the market that feature "plug and play" capability with integrated cooling and control systems, these containerised mines can be delivered by truck and crane and are generally co-located on the power plant premises to reduce connection costs. A commercial shipping port is operational at Little Bay that could facilitate delivery. This would appear to be the most practical option given Montserrat's location.

A desktop assessment of costs is given below:

Description	No.	Unit Cost	Total
Integrated air-cooled mining ISO container	1	$35,000[21] - $90,000[22]	$35,000 - $90,000
3.5kW S21-type mining rig	143	$4,600[23]	$658,000
Groundworks & installation	TBC		
Shipping	TBC		
Grid Connection	TBC		

The hardware costs appear to be in the region of $700,000. Costs for shipping, delivery, installation and connection are unclear, but they should be relatively low due to the "plug and play" nature of the mine.

The longevity of the rigs is harder to account for, and is a function of the global hashrate and how long the mining rigs remain competitive. The rigs themselves generally have productive lifespans of 3-5 years[24]. Renewal of the rigs must be factored into the through-life costs of the system. However, given the zero marginal cost of electricity, the Bitcoin mine in Montserrat would be amongst the most globally competitive. And given the projected six or seven figure annual revenues, it seems probable that the mine would pay for itself quickly and remain profitable in all but the most adverse of markets.

Taking an estimated capital cost of $700k, the medium revenue forecast, 4 year rig life and a

[20] UN Trade & Development figures, 2023

discount rate of 3%, this gives a Net Present Value (NPV) of $1.11m over a 4-year rig lifecycle.

Secondary Benefits

The biggest benefit of the proposed mine will be the enablement of the geothermal project itself and a step-change energy transformation.

The benefits of this are enormous - Montserrat would go from a majority fossil-powered nation to one that is almost entirely renewable-powered overnight. Aside from the obvious benefits in carbon reduction, it would significantly improve the local economy through a dramatic decrease in energy bills, freeing up disposable income to be spent on the island instead of sent abroad to pay oil producers, never to return.

The impact of a decrease in utility costs should not be underestimated - this would mean a lower cost of living, lower business overheads and greater spending in the local economy. It would open up the potential for novel new businesses, particularly eco-tourism.

The plant would support local jobs and tax revenue, instead of supporting the oil industry abroad.

And additionally, grid resilience would be improved by operating the mine as an "inverse peaker plant" - reducing consumption as primary demand comes online, allowing millisecond responses to primary demand change. Bitcoin mines can reduce their consumption faster than a geothermal plant can increase it.

> "Crypto mining can be a catalyst or market driver for new renewable energy projects.... There are many remote geographic areas where the energy demand market is not large enough to support a utility scale renewable energy site"
>
> *Crypto mining can retire fossil fuels for good. Here's how (Aug 2022) - World Economic Forum*

Ownership Structure

Several ownership options exist that would allow the state to choose its exposure to technical risk and financial risk. State ownership is an option, but there are also structures that allow the funding and operation to be outsourced to free market enterprise.

1. Owner-Operator

Under this model, the Government of Montserrat would access private equity or external government funding on the basis of the strengthened investment case for the geothermal plant, and construct and run a state-owned mine alongside the plant. The state would retain full accountability for the project, its revenue and would be able to control the mine as a demand-side response tool.

2. Grid Access Licence

The government could auction access to the stranded energy, alongside a physical site and connection, similar to the manner in which many renewable projects are privately funded and run. The government would receive a fixed fee in return for a guaranteed minimum quantity of annual energy. Risk, construction and operation would be outsourced to a private operator.

3. Fixed Price Unit Licence

The government could supply stranded energy to a miner at an agreed price per kWh. As there is zero marginal cost to the producer, this creates a "floor price" for energy that will underwrite the investment case for the geothermal plant.

Construction and operation would be outsourced to a private operator, risk would be shared between the state and the operator.

Next Steps

There are three avenues that must be explored further in order to converge upon a mature concept.

1. **Finesse the energy model**

Detailed modelling of daily and seasonal variations in demand and supply needs to be undertaken to build confidence in the peak, average and gross figures for stranded energy. Real demand data must be obtained from Montserrat Utilities Limited and compared with forecast supply of solar and geothermal energy. It may be necessary to engage the services of a specialist energy consultancy.

We also note that the scalability of a Bitcoin mine may incentivise an overbuild of the geothermal plant above the 1.5MW baseline, to enable greater secondary revenue and future-proof supply levels. The cost/benefit of a larger plant should be explored.

2. **Explore ownership, funding and governance options**

The Government of Montserrat will need to make a strategic assessment of funding opportunities and which ownership structures are most appealing. Stakeholder alignment will be a significant task - the system will only work with all its constituent parts funded and delivered.

3. **Engage with Bitcoin miners**

Once a detailed energy model is in place, an optimisation exercise will be required to determine the ideal size of mine (balancing capital expenditure and operating revenue). Experienced Bitcoin mining firms should be able to advise on real costs (including installation and connection), revenues and risk as well as optimisation methods.

Conclusion

Montserrat teeters on the cusp of a renewable energy transformation. Few nations could hope to make such a radical flip to renewable energy in just one step.

The existing electricity grid and geothermal wells offer a remarkable de-risking of the transition, the geothermal plant is the final link in the chain.

Montserrat's size is both a blessing and a curse - the issues of finance and scale preclude the infrastructure investment needed to unlock this potential. But whilst larger nations struggle with political inertia, Montserrat's size affords it a political agility and decisiveness that may allow it to pursue novel strategies to decarbonise much earlier than larger nations.

Given the economic logjam surrounding the geothermal plant, we propose that a formal investment case should be assembled, combining the proposed plant with the secondary revenue of a Bitcoin mine to improve profitability and open up the possibility of private investment or loans.

We also conclude that the geothermal plant is an imperative project for the island regardless of how it is financed and supported, offering significant benefit to the citizens and the economy.

Who We Are

Bitcoin Policy UK brings together the community, policy makers, environmentalists, businesses, energy producers and Bitcoin enthusiasts to explore leveraging this groundbreaking innovation to support UK households, businesses, and communities in a sustainable and innovative way.

Our goal is to demystify Bitcoin and show you how this groundbreaking currency can transform today's world.

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