Powerhouses: A Comparative Analysis of Blockchain-Enabled Smart Microgrids

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For over a century, electricity in the United States has been generated and sold mainly by centralized powerplants. Although this model of power collection and distribution has many advantages, resiliency is a growing problem. Brittle infrastructure and growing complexity have made the nation's power grid less reliable over the past twenty years. Some technologists believe the solution is to go small. In the past five years, small communities in the United States and overseas have built "micro-grids"—networks of roof-top solar panels that store electricity in communal banks of batteries, combined with software that allows homeowners and businesses to buy and sell this electricity from one another. The designers of these systems believe that the private sale of electricity among

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neighbors will carry substantial benefits for the public, including the potential to make electricity more reliable, resilient, and renewable.

A challenge stands in the way, however: how to effectively and securely govern electricity as a shared resource among neighbors. This symposium Article examines how well blockchain—the technology that brought the world Bitcoin—might help solve this problem by tracking electricity production and sales in a neighborhood. This Article examines this question through three case studies of blockchain-enabled microgrids in the United States, Europe, and Australia. We conclude that some types of blockchain technologies could help make the dream of a peer-to-peer energy commons a reality. Widespread adoption of this technology will require the support and cooperation of local, state, and federal regulators and lawmakers, however.

I. INTRODUCTION

In centralized systems, small failures can have far-reaching consequences. When a centralized cloud computing service goes offline, thousands of home security cameras can stop recording footage.[1] When a government halts imports of lithium-ion batteries from a centralized source, production of electric vehicles can grind to a halt.[2] When a central bank implements an unwise fiscal policy, a national economy can skitter into recession.[3] Centralization can be a source of fragility.

Nowhere is the flimsiness of centralization more threatening to human security than in the national electrical grid. In 2003, a tree in suburban Ohio fell on a sagging electrical line, triggering a domino-like chain reaction of system failures that, hours later, plunged the eastern seaboard into darkness.[4] Since then, more frequent blackouts in the United States have threatened public health, safety, and productivity. Every power outage is caused by a unique set of circumstances—a biography of sorts. But behind the particulars, nearly all outages stem in one way or another from the centralized architecture of the U.S. power grid. Power plants deliver electricity to homes and businesses through high-voltage lines that branch out, vein-line, across the countryside, and terminate in familiar wall outlets. Take out a single power plant, or even a critical power line, and the whole system can blink out like an old lightbulb.

Policymakers and the power industry are trying to strengthen the grid by changing it into something new: a distributed, organic, flexible network composed of millions of decentralized power generators and users.[5] This vision of a "smart grid" embraces the idea

1. Kim Lyons, *Nest Cameras Were Down for 17 Hours Because of Failed Server Update*, VERGE (Feb. 25, 2020, 10:32 AM), https://www.theverge.com/2020/2/25/21152534/nest-cameras-outage-google-security [https://perma.cc/J9P5-5RQ9].

2. Nicole Kobie, *As Electric Car Sales Soar, the Industry Faces a Cobalt Crisis*, WIRED (Feb. 20, 2020), https://www.wired.co.uk/article/cobalt-battery-evs-shortage [https://perma.cc/K3HD-3TBK].

3. *See, e.g.*, James A. Dorn, *How Central Banks Cause Financial Crises*, CATO INST. (Aug. 12, 2016), https://www.cato.org/commentary/how-central-banks-cause-financial-crises [https://perma.cc/AR8W-HCAZ] (examining the potential consequences of central banks' economic policies).

4. GRETCHEN BAKKE, THE GRID: THE FRAYING WIRES BETWEEN AMERICANS AND OUR ENERGY FUTURE 134 (2016).

5. *See, e.g.*, SmartGrid.gov, https://www.smartgrid.gov/the_smart_grid/smart_grid.html [https://perma.cc/35A5-3YGC] (predicting that the "Smart Grid will likely bring the same kind of [decentralizing] transformation that the Internet has already brought to the way we live, work, play, and learn").

that electricity can come not solely from large commercial powerplants but also from small "microgrids" in neighborhoods and business districts.[6] Lawrence Berkeley National Laboratory defines a microgrid as "energy generation and energy storage that can power a building, campus, or community when not connected to the electric grid."[7] Microgrids often generate power through roof-top solar panels, store it in large batteries, and distribute it around the block, or perhaps one day, across the county. Such systems in the future might only allow homes and businesses to collect, store, and transact in power locally. The vision is that of a commons: neighbors might someday share electricity the way they share greenspaces, parks, and other commons.

Microgrids could offer some meaningful advantages. By reducing public reliance on large power generators, the smart grid could provide a more resilient energy future. Such a system would also reduce the need to transmit electricity over long distances—a key source of inefficiency in the current grid. As an added benefit, by introducing more solar panels to the power system, the smart grid could reduce the public's reliance on carbon-generating fuel sources like coal and natural gas that many powerplants burn. What's more, microgrids seem more feasible than ever before. Federal and state legislation permits private homes and businesses to generate power locally through roof-top solar panels, and some states require power utilities to buy excess solar energy back from consumers (this practice is called "net metering").[8] With some adjustments to infrastructure, these power sources could be used to transmit power to neighbors rather than back to utility companies.

A barrier stands in the way of community-based microgrids, however: a system for mediating transactions between neighbors. If neighbor "A" wishes to buy 100 kilowatts of power from neighbor "B," how should they agree on a price? How should payments be handled? How can such a system mediate thousands of transactions every day between neighbors who don't necessarily know one another? If microgrids are to serve as reasonable alternatives to plant-generated power, they must allow for transactions that are automatic, low cost, private, and often between neighbors who don't know one another. Looming behind the myriad technological questions this problem raises is an old and familiar human problem: trust. How can we trust people who we might not know well to pay us what we're owed and to deliver what they've promised? As Nobel Laureate Elinor Ostrom once remarked, "[t]rust is the most important resource."[9]

Some technologists believe that blockchain technology, the decentralized software that brought the world Bitcoin, is the answer to this puzzle. Although there is ample (and reasonable) skepticism about the utility of blockchain technology in many settings, its use in this context makes some intuitive sense. The microgrids that technologists envision follow the model of a shared common-pool resource—a model that eschews centralized command-and-control in favor of ground-up cooperation. Blockchain is, at its heart, a

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6. *See How Microgrids Work*, U.S. DEP'T OF ENERGY, https://www.energy.gov/articles/how-microgrids-work [https://perma.cc/XA6W-PKVT] (describing microgrid technology).

7. Grid Integration Group, *Microgrids and Vehicle-Grid Integration*, BERKELEY LAB, https://gridintegration.lbl.gov/microgrids-vehicle-grid-integration.

8. *See State Net Metering Policies*, NAT'L CONF. ST. LEGISLATURES (Nov. 20, 2017), https://www.ncsl.org/research/energy/net-metering-policy-overview-and-state-legislative-updates.aspx [https://perma.cc/DM2Z-34ZT] (outlining net metering policies by state).

9. *Interview with Nobel Laureate Elinor Ostrom*, ESCOTET FOUND., https://escotet.org/2010/11/interview-with-nobel-laureate-elinor-ostrom/ [https://perma.cc/RQ4K-QZBZ].

system that allows for decentralized transactions between peers. Proponents often call the system "trustless" because it removes the need for parties to a transaction to trust one another—they need only trust the protocol. Many industry experts already believe that blockchain will soon decentralize and bring resiliency to secure supply chains,[10] property transactions,[11] and financial services.[12] Without a decentralized transactional system of some kind, consumers seeking to buy and sell power from each other would need to rely on a middleman of some sort. This would introduce centralization to the smart grid—a system premised on the idea of decentralization.[13] To put it more simply, it makes intuitive sense for a decentralized grid to have a decentralized metering and payment system.[14]

Of course, there's often a gap between theory and practice. Legal scholars have written helpfully and hopefully on theoretical uses of blockchain technology in the smart grid of the future.[15] Technical experts have described how the technology might be put to use in theory. There are some obvious practical questions, however: for instance, public blockchains such as the Bitcoin network have sparked widespread concern for the massive amounts of electricity they consume. It seems natural to wonder if the energy costs of blockchains might exceed any design benefits they could offer the electrical grid. There have been very few empirical studies examining how blockchain-based microgrids are working in practice, however. Similarly, few scholars have explored what bearing law and policy might have on the use of this technology.

This Article builds upon the current literature by examining two questions: (1) is blockchain a useful governance mechanism for managing electricity as a shared pool resource?; (2) what steps, if any, might policymakers wish to take in response to this emerging technology? We think these questions are important. If blockchain-based microgrids can improve electrical service, then policymakers may wish to take steps to encourage their adoption and to remove legal barriers to their use. On the other hand, if this technology is unlikely to deliver the benefits that its supporters hope for, government and private industry might better direct their energies to different solutions.

This symposium contribution examines the foregoing questions by investigating blockchain-powered microgrids located in Brooklyn, NY, Switzerland, and Australia. Our

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10. *See* Scott J. Shackelford et al., *Securing the Internet of Healthcare*, 19 MINN. J.L. SCI. & TECH. 405, 418–20 (2018) (arguing that blockchain can improve supply chain management and security).

11. *See* Nir Kshetri, *Blockchain-Based Property Registries May Help Lift Poor People out of Poverty*, CONVERSATION (June 28, 2018, 6:36 AM), https://theconversation.com/blockchain-based-property-registries-may-help-lift-poor-people-out-of-poverty-98796 [https://perma.cc/TQ3Z-GCDC] (arguing that blockchain can help securely record property ownership).

12. *See* Mayank Pratap, *How Is Blockchain Revolutionizing Banking and Financial Markets*, HACKERNOON (July 30, 2018), https://hackernoon.com/how-is-blockchain-revolutionizing-banking-and-financial-markets-9241df07c18b [https://perma.cc/3GKC-WLMM] (noting that blockchain could transform the finance and banking sectors by reducing costs).

13. *See* Scott J. Shackelford & Steve Myers, *Block-by-Block: Leveraging the Power of Blockchain Technology to Build Trust and Promote Cyber Peace*, 19 YALE J.L. & TECH. 334, 339–50 (2017) (describing how Bitcoin works and contrasting it with centralized banking systems).

14. *See, e.g.*, Scott J. Shackelford, *The Future of Frontiers*, 23 LEWIS & CLARK L. REV. 1331, 1359 (2020) (describing evidence supporting "the view that global problems are best treated through regional cooperation that includes smaller and more manageable numbers of participants").

15. *See* Claire Henly et al., *Energizing the Future with Blockchain*, 39 ENERGY L.J. 197, 197 (2018) (proposing that blockchain could transform the electric power industry).

goal is modest and largely descriptive (rather than normative): we wish to offer readers a first step toward better understanding blockchain technology as a governance mechanism in energy commons. The discussion is high-level and geared toward readers without prior knowledge of how electrical delivery or blockchain technologies work. We hope the discussion will serve as a foundation for more in-depth empirical work and policy analysis in the future.

This Article is structured as follows: Part II provides an overview of the smart grid and blockchain technology. Part III features a comparative microgrid case study. Part IV analyzes the findings from these case studies in light of the legal and regulatory landscape. Part IV places a heavy emphasis on the security, environmental, and transactional dimensions of microgrid use. We conclude with a summary and preliminary policy suggestions. We also offer a research agenda for further work to more fully unpack the myriad governance challenges and opportunities presented by deploying blockchain tech in the energy sector.

II. Background on Microgrids and Blockchain

This Part describes how and why the electrical grid—arguably the largest and most complicated machine ever built—is changing into a smart grid. Like "open source" or "blockchain," the term "smart grid" doesn't describe a single technological protocol but rather a new way of doing things. The smart grid emerging around us today is built from technology, laws, regulations, and transactions. Beneath those visible layers are new beliefs about how electrical power should be governed. The watchwords of this philosophy are "decentralized," "resilient," and "participatory." As liberating as the idea sounds, the smart grid faces some significant challenges. Chief among these is how to enable homes and businesses to buy and sell energy from each other at the local level. This Part begins with an explanation of how our electrical system works today at a high level. It then describes the optimistic vision of the smart grid and what role blockchain might play in the future.

A. The Once and Future Grid

In the beginning, every grid was a microgrid. When electricity first came to the public in the late 19th century, the only electrical grid in existence was a kit-like product sold by Thomas Edison.[16] For a price that only businesses and wealthy individuals could pay, Edison and his employees would install everything needed to generate power and light for a single building.[17] These "private plants," as they were called, included two coal-burning generators, copper wire sheathed in insulation, and the lightbulbs for which Edison famously received a patent.[18] Businesses purchased these kits to run factories and offices. Cities purchased them to light public spaces.[19]

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16. Bakke, *supra* note 4, at 36 ("Edison's grid was thus rather like a kit . . . .").

17. *Id.*

18. *Id.*, at 36–38.

19. *Id.*; *see generally* Vaclav Smil, Energy and Civilization: A History (2017) (examining the interplay between energy and society from nomadic peoples up to industrial states); Peter Fox-Penner, Smart Power: Climate Change, the Smart Grid, and the Future of Electric Utilities (2010) (considering the U.S. energy grid's future in the face of climate change and security threats).

Two problems plagued the early Edison grids: their coal-burning generators polluted the air, and by design, they had to be located close to where people lived and worked. This was because, at the time, there was no feasible way to transmit power across long distances. A potential solution to the first problem—pollution—was arrived at in the city of Appleton, Wisconsin. There, a wealthy investor arranged to install an Edison grid situated over the Fox River, the largest tributary of Lake Michigan. Rather than relying on the energy of burning coal, the system was powered by the mechanical power of naturally flowing water. The Vulcan Street grid, as it was named, was the country's first hydroelectrical powerplant. It was also the first municipal grid. In addition to powering businesses, it delivered light to nearby homes.

The problem of long-distance transmission was solved with the invention of alternating current (AC) in the 1890s.[20] The physics behind alternating current is complicated, but the underlying idea is easy to understand. Imagine a necklace strung all the way around with pearls. If you set the necklace down on a tabletop and push one pearl clockwise, all of the other pearls in the necklace will move around in a neat circle—a circuit. This is a simple way to visualize the route that electrons followed in Edison's old direct current ("DC") kits. The major downside to DC power, as Edison discovered, is that it doesn't travel very far (just imagine trying to push a mile-long string of pearls around!). There's another way to transmit energy through a wire, though: instead of pushing the electrons around in a circuit, vibrate them back and forth quickly. Individual electrons no longer traverse the whole loop, but the energy put into the system does. This is alternating current (AC), and unlike DC power, it can be sent across long distances.

The ability to send electricity across the countryside made another important change to the grid possible: interconnection, and with it, the consolidation of industrial and economic power. If the early days of commercial electricity followed the model of small disconnected islands, the model that arose in the early 20th century was that of a bustling city. This change was the vision of the Chicago industrialist, Thomas Insull. As Gretchen Bakke describes in her book, *The Grid*, by delivering power to many kinds of customers, Insull was able to make money at more times of day:

> Instead of many little generating stations, with many owners, running intermittently, [Insull] wanted one that he owned and which ran all the time . . . . He needed streetcar companies to buy from him at dusk and dawn, residential customers for the late evenings and early nights, municipal street lights for nighttime, businesses for the late afternoons and early evenings, and most important of all, industry for midday.[21]

Insull brought mass electrification to Chicago, and his model for delivering power to customers who needed it at different times of day was replicated across the United States. Together, AC power and Insull's vision of mass electrification led to the infrastructure we live with today: high voltage wires stretching across the countryside and power transformers installed on the outskirts of towns, the tops of utility poles, and

20. *See generally* THOMAS PARKE HUGHES, NETWORKS OF POWER: ELECTRIFICATION IN WESTERN SOCIETY, 1880–1930, 106–39 (1983) (describing late 19th century advancements and discoveries in electricity).

21. BAKKE, *supra* note 4, at 66.

underground.[22]

Insull's legacy was to distribute electric power and to concentrate economic power. In most of the country today, power is generated and delivered by electrical utility companies that function as monopolies across wide geographic regions.[23] Their names are familiar—Duke, ConEd, PG&E, to name a few. Most of these companies are owned by investors and regulated by state and federal governments. One level up, a small set of corporations called balancing authorities help to coordinate supply and demand geographically.[24] If supply and demand don't match perfectly throughout a day, power might be unavailable or overload part of the grid. The interstate transmission and wholesale of electricity are overseen by regional grid operators.

Over the past twenty years, the public has had a growing awareness of the downsides of this model of mass interconnection. First, large blackouts are occurring more often and taking longer to fix.[25] As mentioned in the Introduction, a tree falling on a sagging electrical line in suburban Ohio set off a chain reaction that resulted in a massive blackout across the east coast in 2003.[26] More common, however, are the small, intermittent blackouts that occur in parts of the country where infrastructure is not regularly kept up, such as Detroit, MI.[27] Reliability is a security problem, both at a national level and at a human level. As Amory and L. Hunter Lovins wrote 1982:

> The energy that runs America is brittle—easily shattered by accident or malice. That fragility frustrated the efforts of our Armed Forces to defend a nation that literally can be turned off by a handful of people. It poses, indeed, a grave and growing threat to national security, life, and liberty.[28]

Alongside the unreliability of the grid is the fact that our centralized electrical system relies heavily on the burning of coal and natural gas. In terms of return on energy investment, these fuels are remarkably efficient. That is, the energy required to extract, refine, and burn them is dwarfed by the amount of power they generate. Despite their efficiency, however, these fuels are a major source of carbon emissions into the atmosphere. As of 2020, there is a nearly unanimous consensus within the scientific community that, through the greenhouse effect, atmospheric carbon is causing global

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22. Sarah Gerrity & Allison Lantero, *Infographic: Understanding the Grid*, U.S. DEP'T. ENERGY (Nov. 17, 2014), https://www.energy.gov/articles/infographic-understanding-grid [https://perma.cc/QF9W-37FC].

23. BAKKE, *supra* note 4, at 57–60.

24. *See Electricity Explained: How Electricity Is Delivered to Consumers*, U.S. ENERGY INFO. ADMIN. (Oct. 22, 2020), https://www.eia.gov/energyexplained/electricity/delivery-to-consumers.php [https://perma.cc/TR7F-RYEP] (explaining how balancing authorities manage grid operations).

25. *See, e.g.*, Ula Chrobak, *The US Has More Power Outages Than Any Other Developed Country. Here's Why.*, POPULAR SCI. (Aug. 17, 2020), https://www.popsci.com/story/environment/why-us-lose-power-storms/ (analyzing blackouts within the United States).

26. BAKKE, *supra* note 4.

27. *See* Alyson Kenward & Urooj Raja, *Blackout: Extreme Weather, Climate Change and Power Outages*, CLIMATE CENT. 15–16 (2014), https://www.ourenergypolicy.org/wp-content/uploads/2014/04/climate-central.pdf [https://perma.cc/64HG-A4GV] (reporting 34 weather-related blackouts for the Detroit Edison Utility between 2003–2012, affecting an estimated 4.98M customers); *see also* Patti Waldmeir, *Michigan: A Tale of US Neglect*, FIN. TIMES (Mar. 14, 2021), https://www.ft.com/content/39afe201-09af-42e2-b611-6d16dcdaa2f3 [https://perma.cc/4GTB-ZR75] (discussing decaying electrical infrastructure in Michigan).

28. AMORY B. LOVINS & L. HUNTER LOVINS, BRITTLE POWER: ENERGY STRATEGY FOR NATIONAL SECURITY 1 (Brick House Publ'g 1982).

warming. Continued global warming is expected to lead, both directly and indirectly, to wide-scale loss of life and economic harm. Increased heatwaves, droughts, wildfires, agricultural shortages, and more violent weather are the most likely results.[29] As a result, a portion of the public has expressed enthusiasm for more sources of electricity that are sustainable. Many are concerned by the economic costs of flipping the switch to new and greener sources of electricity, however. The extraction of energy from fossil fuels is a significant source of jobs and security for millions of Americans.[30] Many of these jobs have helped the country's middle class. This is why so many policy debates about fossil fuels have mostly focused on comparing the costs and benefits of job creation to those of reducing the levels of CO2 in the atmosphere.

The two problems outlined in the foregoing paragraphs—the reliability of the grid and the impact of atmospheric CO2—have inspired a new vision for power delivery no less radical than Insull's mass electrification. This vision is generally referred to as the smart grid, and it includes a variety of technologies and concepts. Chief among these are:

- A massive two-way data connection between power users and power suppliers. These data would include, for instance, information about when a home has used power and how much it has used. Such data might also include the readings from electronic sensors designed to detect faults in the power infrastructure.
- Software that uses these data to help utility companies better predict demand for power throughout a day and regions of a grid that might soon break.
- Powerplant-generated power supplemented by local power sources, such as roof-top solar panels on homes and businesses.
- The ability of home and business owners to sell excess locally generated power back to the power companies.
- The ability of home and business owners to sell excess locally generated power to neighboring homes and businesses through a "micro-grid."[31]

In his book, S*mart Power*, Peter Fox-Penner sums up the essence of the smart grid eloquently:

> This term has been used quite broadly in many ways, but what it really means is combining time-based prices with the technologies that can be set by users to automatically control their use and self-production, lowering their power costs and offering other benefits such as increased reliability to the system as a whole.[32]

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29. *See* EXEC. OFF. OF THE PRESIDENT, ECONOMIC BENEFITS OF INCREASING ELECTRIC GRID RESILIENCE TO WEATHER OUTAGES 3 (2013) ("Grid resilience is increasingly important as climate change increases the frequency and intensity of severe weather.").

30. *See* 2017 U.S. ENERGY AND EMPLOYMENT REPORT, DEP'T ENERGY (Jan. 13, 2017), https://www.energy.gov/downloads/2017-us-energy-and-employment-report [https://perma.cc/G6XR-L6LA] (reporting that in 2016, about 1.1 million U.S. jobs in the power sector "worked in traditional coal, oil, or gas").

31. *See* FOX-PENNER, *supra* note 19, at 34 (detailing the goals of developing a smart grid).

32. *Id.*

In other words, the vision of a smart grid is premised on the notion of exchange. Where Thomas Insull made us all consumers of power generated far away, the smart grid promises to allow us to produce power locally for ourselves and to sell it to whomever we wish. How best to achieve that vision is an open question, however.

B. Blockchain: An Internet of Electricity?

Despite the volatility of cryptocurrency markets,[33] the underlying technology powering the likes of Bitcoin—blockchain—has been gaining support from respected investors and institutions. Well-known Silicon Valley venture capital firms such as Andreesen Horowitz have made significant investments into blockchain-based projects.[34] In 2020 and 2021, the prices of cryptocurrencies skyrocketed, partly in response to large institutional investors adding these assets to their investment portfolios.[35] Crypto markets are unpredictable and volatile. At the moment though, these developments seem to validate Goldman Sachs' 2016 prediction that the technology could "change 'everything.'"[36]

Blockchain technology is complex, but the underlying idea is simple. As The Economist explained in 2015, a blockchain is a "shared, trusted, public ledger that everyone can inspect, but which no single user controls."[37] Blockchain participants—computer users who run the same blockchain network protocol over the internet—each maintain a copy of the shared ledger and work together to keep all of their copies consistent. This is accomplished through a software-based consensus algorithm.[38] The result is that all of the members of the network agree on what the shared ledger looks like. By serving as a record of ownership, a ledger makes it impossible for two people to claim ownership of the same thing. In Bitcoin's blockchain ledger, the consensus process "prevents double-spending and keeps track of transactions continuously," which is "what makes possible a currency without a central bank."[39] One expert recently called blockchains "the latest example of the unexpected fruits of cryptography."[40]

Blockchains could solve many problems in the power industry. Today, many power

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33. *See, e.g.*, Nathan Reiff, *Why Bitcoin Has a Volatile Value*, INVESTOPEDIA (June 16, 2020), https://www.investopedia.com/articles/investing/052014/why-bitcoins-value-so-volatile.asp [https://perma.cc/NX2L-3CXZ] (describing the factors that make Bitcoin a volatile investment).

34. Connie Loizos, *Andreessen Horowitz Has a New Crypto Fund—And Its First Female General Partner Is Running It with Chris Dixon*, TECHCRUNCH (June 25, 2018, 3:03 PM), https://techcrunch.com/2018/06/25/andreessen-horowitz-has-a-new-crypto-fund-and-its-first-female-general-partner-is-running-it-with-chris-dixon/ [https://perma.cc/4TBC-5UAB].

35. Kevin Helms, *JPMorgan's Analysis Shows Institutional Investors Moving from Gold ETFs to Bitcoin*, BITCOIN.COM: NEWS (Nov. 9, 2020), https://news.bitcoin.com/jpmorgan-gold-etfs-bitcoin/ [https://perma.cc/U722-RRSB].

36. Naomi Lachance, *Not Just Bitcoin: Why the Blockchain Is a Seductive Technology to Many Industries*, NPR (May 4, 2016, 7:01 AM), http://www.npr.org/sections/alltechconsidered/2016/05/04/476597296/not-just-Bitcoin-why-blockchain-is-a-seductive-technology-to-many-industries [https://perma.cc/QEH9-BHFY].

37. Jon Berkeley, *The Trust Machine*, ECONOMIST (Oct. 31, 2015), http://www.economist.com/news/leaders/21677198-technology-behind-Bitcoin-could-transform-how-economy-works-trust-machine [https://perma.cc/949B-Y2CF].

38. *See* Shackelford & Myers, *supra* note 13, at 340 (explaining how bitcoin works); Berkeley, *supra* note 37 (explaining that Bitcoin's blockchain has large potential for the economy).

39. Berkeley, *supra* note 37.

40. *Id.*

companies purchase credits and renewable energy certificates for green energy from businesses that generate green power.[41] Critics have argued that the market for these certificates is opaque, making it difficult to verify that the electrical power represented on a certificate was truly generated by sustainable means.[42] By recording the energy produced and purchased through a trusted blockchain, a power company would have a clearer record of how the power was created. As Andrew Winston has explained, this type of "tamperproof database" could "mak[e] tracking [energy] more granular, automated, and trusted."[43] This could help promote carbon neutrality and efficiency by avoiding the double-counting of renewable energy credits.[44]

Some experts believe that blockchains can also promote the streamlining and financing of renewable energy projects.[45] A San Francisco-based firm called Banyan Infrastructure Corporation, for example, is using blockchain technology to lower administrative costs to help make small-scale solar energy projects economically viable.[46] In the future, blockchain might also help lower capital requirements by minimizing the perceived risk of renewable energy projects to investors.[47]

Perhaps blockchain's greatest impact, though, will be to help decentralize power, bringing consumers of electricity closer to generators. Many homes and businesses in the United States adopted solar panels over the past decade. Presently, consumers who own panels can either use the power themselves or sell it back to their utility companies.[48] Imagine, though, if a neighborhood or business district could pool the electricity generated by each building in local banks of batteries. Homes that don't have panels could then buy electricity locally from the community power supply—perhaps at lower rates than the utility company sets.

Such a return to local power generation and consumption could bring important benefits. First, a microgrid would remove inefficiencies (in the form of electrical power loss) associated with sending power over long distances. Second, by vastly increasing the number of independent power generators, a national tapestry of microgrids could reduce the harm that any single hack could cause compared to the current model. No longer could a single tree falling on a power line cause vast, sprawling power outages. Third, this system could increase the number of renewable energy sources in the national grid.

Of course, a local electricity market wouldn't only require electrical infrastructure but also a financial record-keeping system. To calculate what homeowners who contribute to the pool should be compensated, it would be necessary to have a record of how much electricity each generated. To set prices, it would also be necessary to have a clear picture

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41. Andrew Winston, *Blockchain and the Clean, Smart Grid*, MIT SLOAN MGMT. REV. (May 8, 2018), https://sloanreview.mit.edu/article/blockchain-and-the-clean-smart-grid/ [https://perma.cc/GFQ7-KGKN].

42. *Id.*

43. *Id.*

44. *Id.* At the moment, the only option that most consumers have to purchase carbon neutral electricity is through purchasing "energy credits" offered by electricity utility companies. These credits contribute to a fund that electrical utility companies use to generate electricity from solar power or wind.

45. *Id.*

46. Winston, *supra* note 41.

47. *Id.*

48. *See Homeowner's Guide to Going Solar*, U.S. DEP'T OF ENERGY, https://www.energy.gov/eere/solar/homeowner-s-guide-going-solar [https://perma.cc/HUT8-SQVW] (outlining how installing solar panels can save consumers money).

of the community's supply and demand for power at any time. Moreover, the system would need to be able to automatically credit and debit homeowners based on their purchases. A blockchain could be an ideal system for maintaining a trustworthy record of this sort. As Andrew Winston has argued, "[m]illions of individual devices and building systems could track their needs and trade electricity device to device, across the full grid, or on small, localized microgrids. Blockchain's shared, tamperproof ledger could verify all transactions, creating a new kind of energy market."[49]

Although a blockchain-enabled microgrid might sound like a fanciful idea, it is already being used in practice. The following section tells the stories of three communities that are already using the technology in the United States, Switzerland, and Australia.

III. CASE STUDIES

This Part briefly compares three community blockchain-enabled microgrids in the United States, Europe, and Australia. Unlike municipal or corporate microgrids, these projects require individual energy uses to buy and sell power from one another. For this symposium contribution, we have intentionally presented these case studies as brief, preliminary surveys. Our hope is that this format will generate useful discussions among the symposium participants and demonstrate the need for more robust empirical studies.

A. Brooklyn, NY

Among the reportedly more than 2,250 microgrids across the United States (as of 2018),[50] one of the most well-known is in Brooklyn, NY. The Brooklyn Microgrid is the result of a partnership between L03 Energy, a New York-based blockchain energy startup,[51] and Siemens, one of the world's largest producers of energy-efficient technologies.[52] Since its launch in 2016, the Brooklyn Microgrid has developed rapidly. The project was tested on a single street in 2016 and quickly expanded into the surrounding neighborhoods of Gowanus and Park Slope.[53] Electricity is collected by privately-owned roof-top panels, stored in large batteries, and transferred automatically during the month based on consumer supply and demand. The system uses a private blockchain as a settlement mechanism to streamline transactions between neighbors and to provide transparency (e.g., on pricing, supply, and demand) to the microgrid's community.[54] The blockchain is distributed across home computers and smart meters in the neighborhood.

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49. *Id.*

50. *See* Molly Lempriere, *Smart Neighbourhood, Smart Microgrid*, ENERGY STORAGE (Apr. 27, 2020 10:37), https://www.energy-storage.news/blogs/smart-neighbourhood-smart-microgrid [https://perma.cc/P6JX-CZAK] (stating that there were 2,250 microgrids in the United States in 2018).

51. Press Release, Siemens AG & LO3 Energy, Siemens Invests in LO3 Energy and Strengthens Existing Partnership (Dec. 19, 2017), https://lo3energy.com/siemens-invests-lo3-energy-strengthens-existing-partnership/ [https://perma.cc/Z4UX-UCAA].

52. *About Us*, SIEMENS, https://new.siemens.com/global/en/company/about.html [https://perma.cc/5UJ9-QAYS].

53. *The Brooklyn Microgrid: Blockchain-Enabled Community Power*, POWER TECH. (Dec. 23, 2019), https://power-technology.com/features/featurethe-brooklyn-microgrid-blockchain-enabled-community-power-5783564/ [https://perma.cc/ENY5-CYLK] [hereinafter *The Brooklyn Microgrid*].

54. *Id.*

Importantly, the system allows community members to stay connected to the main power grid, which makes it possible for them to choose to draw power from the utility company or from the microgrid. The system can also operate in "island mode" during crises such as a blackout.[55]

To better understand how this system works, it's helpful to look at what a transaction looks like. The community is composed of "prosumers"—people who own power generation and storage equipment—and "consumers"—people who wish to purchase excess electricity collected by prosumers. Prosumers own special wirelessly connected energy meters that track how much electricity they have available at any time. The private blockchain is sustained by these energy meters. Using a mobile app provided by LO3, consumers are able to automatically bid on available electricity, and prosumers are able to issue sell orders.[56] The bid and ask orders are sent to a smart contract—a piece of software that can automate transactions—distributed across the blockchain. Deals are struck automatically, based on buyer and seller preferences. As a recent study of the Brooklyn Microgrid explains, "consumers constantly bid their maximum price limit for their preferred energy sources (e.g., local renewable energy)," and "[p]rosumers bid the minimum price limit that they request for selling their generation on the microgrid market."[57] When a transaction occurs—i.e., when a buyer and seller are matched—a new block is added to the blockchain, containing the current market price, the buyer and seller's blockchain account addresses, and the amount of power exchanged.[58]

The Brooklyn Microgrid demonstrates some unexpected advantages of this technology.[59] One advantage is that the system appears to be incentivizing community members to purchase solar panels. This incentive stems from the fact that one can draw a profit by selling power through peer-to-peer transactions with the community.[60] A second advantage is that this system appears to improve resilience. This is because localized energy sources are more reliable on average than bulk power generation, given the propensity of long transmission lines to be damaged,[61] a danger that might only increase as a result of climate change.[62] Finally, the Brooklyn Microgrid can also help protect civilian critical infrastructure by allowing energy to be directed toward hospitals and community centers in emergencies.[63]

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55. Lawrence Orsini et al., *How the Brooklyn Microgrid and TransActive Grid Are Paving the Way to Next-gen Energy Markets*, *in* WOODHEAD PUBL'G SERIES IN ENERGY, THE ENERGY INTERNET: AN OPEN ENERGY PLATFORM TO TRANSFORM LEGACY POWER SYSTEMS INTO OPEN INNOVATION AND GLOBAL ECONOMIC ENGINES 230–34 (Wencong Su & Alex Q. Huang eds., 2018).

56. *See generally* Esther Mengelkamp et al., *Designing Microgrid Energy Markets: A Case Study: The Brooklyn Microgrid*, 210 APPLIED ENERGY 870 (2018) (describing the tools available to prosumers).

57. *Id.*

58. *Id.*

59. *Id.*

60. *Id.*

61. *See* Harrison John Bhatti & Mike Danilovic, *Making the World More Sustainable: Enabling Localized Energy Generation and Distribution on Decentralized Smart Grid Systems*, 6 WORLD J. ENG'G & TECH. 350, 365 (2018) (noting the lack of adaptability of the traditional power grid structure to "disturbances" and its relative vulnerability to "cyber and physical risks").

62. *See* U.S. DEP'T OF ENERGY, CLIMATE CHANGE AND THE ELECTRICITY SECTOR: GUIDE FOR CLIMATE CHANGE RESILIENCE PLANNING 7 (2016) (identifying goals to develop a climate change resistant energy model).

63. *The Brooklyn Microgrid*, *supra* note 53.

The leaders of the Brooklyn Microgrid project have reported that their greatest challenge they've faced so far is regulatory; in New York State, entities that sell electricity are typically regulated as utility companies—a categorization that carries myriad legal requirements.[64] These requirements were designed by policymakers with traditional utility companies in mind, and they often do not address the unique dynamics of a blockchain-based microgrid. This topic is explored in greater detail later in this paper.

As of 2020, there were approximately fifty customers, including homes and businesses, comprising the Brooklyn Microgrid.[65] Expansion plans beyond this scale are unclear as of this writing, but the concept seems to be catching on both across the United States and abroad, including in Australia.

B. Australia

Mooroolbark, a suburb of Melbourne, has demonstrated how eighteen houses can operate on their own solar panels and battery storage for up to twenty-two hours.[66] Outside of Melbourne, Monash University's Clayton campus is being turned into a microgrid as another proof of concept as part of its Net Zero Initiative with the goal of zero net carbon emissions by 2030.[67] In partnership with the tech firm Indra, the university has built a local electricity network and trading market with linkages to the external energy network.[68] Although the total number of customers is uncertain, the Smart Energy City will include the control of distributed energy resources, including a minimum of 1 MW solar panels, twenty buildings, electric vehicle charging stations, and 1MWh of energy storage.[69] The technical details of the project appear in Figure 1, but it includes real-time demand information and voltage control. The stakeholders for the Monash Microgrid are included in Figure 2.[70] It is too soon to tell how successful the Monash Microgrid has been, as the project is still underway as of this writing. It is being supported by the Victorian Government as part of its Microgrid Demonstration Initiative and was begun in 2019 with a growth plan through 2020.[71]

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64. *Id.*

65. Lempriere, *supra* note 50.

66. Bjorn Sturmberg, *Micrograds: How to Keep the Power on When Disaster Hits*, CONVERSATION (Feb. 10, 2020, 2:11 PM), https://theconversation.com/microgrids-how-to-keep-the-power-on-when-disaster-hits-130534 [https://perma.cc/LZ87-W3J5]. Similarly, the ESCRI project in South Australia "can provide electricity indefinitely for 4,600 customers." *Id.*

67. Jess Davis, *Microgrids and Neighbourhood Power Sharing Set to Transform How We Use Energy*, ABC NEWS (Dec. 4 2019, 12:28 AM), https://www.abc.net.au/news/rural/2019-12-03/microgrids-set-to-transform-how-we-use-energy/11756672 [https://perma.cc/RT8L-7AT9]; *Net Zero Initiative*, MONASH UNIV., https://www.monash.edu/net-zero-initiative [https://perma.cc/FZ3J-9Z49].

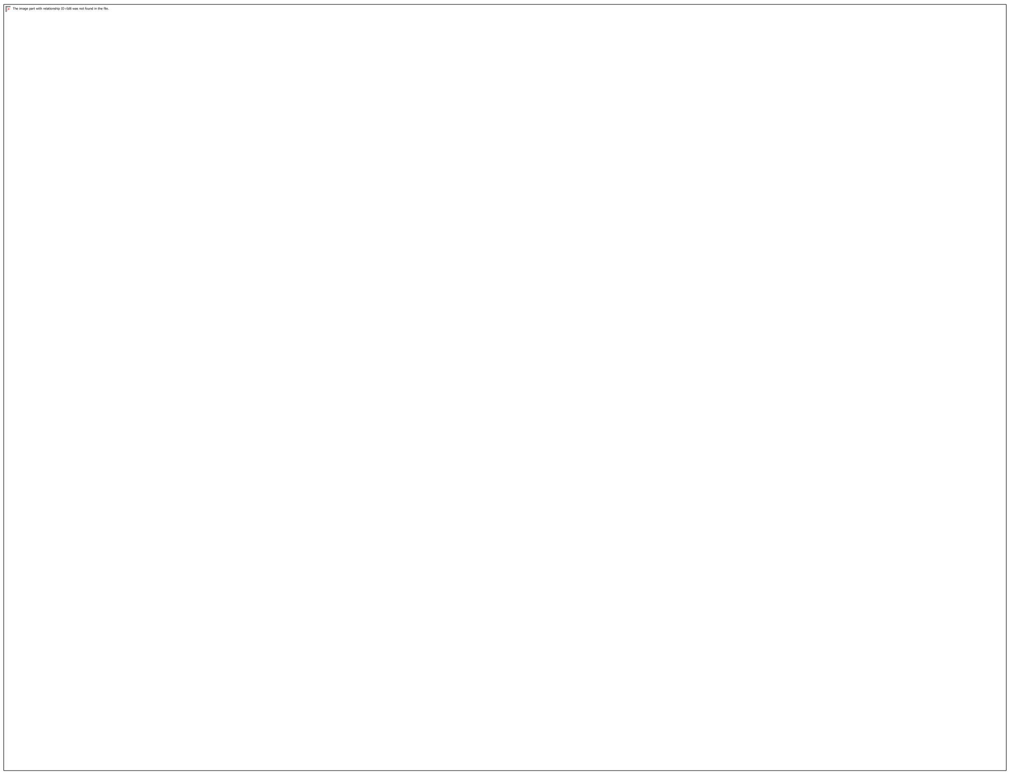
68. PATRICIA BOYCE ET AL., VICTORIAN MARKET ASSESSMENT FOR MICROGRID ELECTRICITY MARKET OPERATORS 3 (2019), https://www.monash.edu/__data/assets/pdf_file/0010/1857313/Monash-Net-Zero_Microgrid-Operator-Whitepaper_20190617-1.pdf [https://perma.cc/KCN3-55NF].

69. *Id.* at 89.

70. *Id.* at 42, 78 (noting that if the Monash University microgrid extends to supply third parties with electricity, such as food and service providers on campus, then the university will have to register with the Essential Services Commission (ESC) and Australian Energy Regulator (AER) to obtain exemptions from holding a license and Australian Energy Market Operator (AEMO) registration).

71. Monash Univ., MICROGRID ELECTRICITY: MARKET OPERATIONS (May 2019), https://www.monash.edu/__data/assets/pdf_file/0011/1980497/Monash-Net-Zero_Microgrid-Operator-

Figure 1: Monash Microgrid Functionality[72]



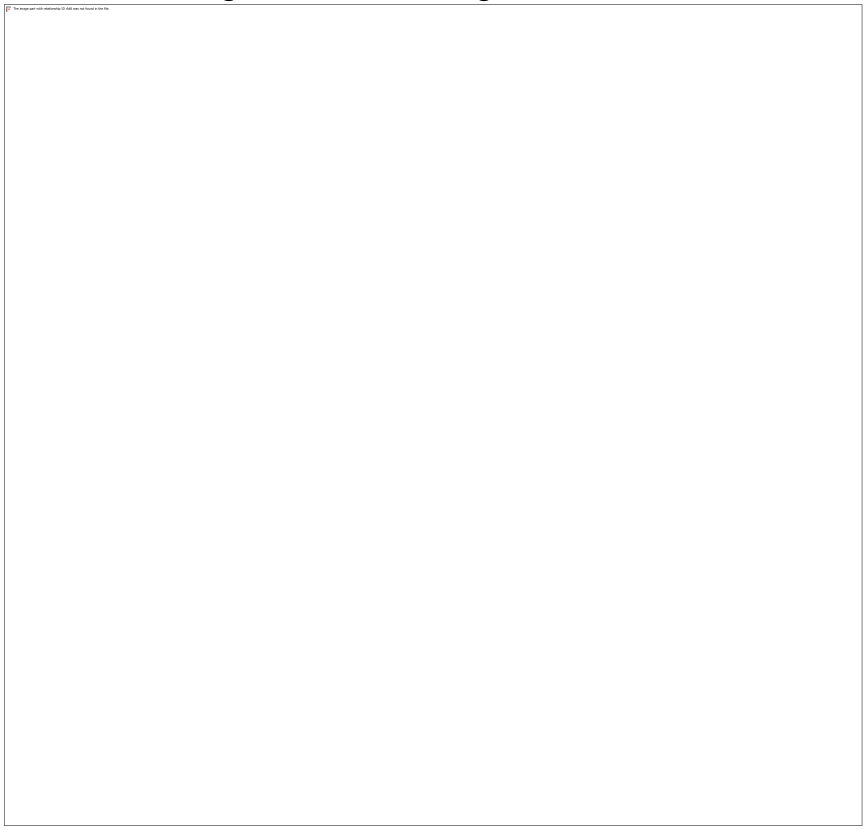
Commercialisation-Brochure_20190617.pdf [https://perma.cc/66CZ-DFT2]; BOYCE ET AL., *supra* note 68, at 8. For 2019, these goals included:

> Establish mechanics for MEMO based on Monash Microgrid model; Help inform regulators and policy makers by testing energy trials at Monash; Refine MEMO model; Formalize strategic partnering relationships in contract; Identify potential sites for further roll-out of MEMO; Market the MEMO model with the aim if contracting the next microgrid project; Begin feasibility assessment and commercial negotiations for MEMO next microgrid projects.

Id.

72. BOYCE ET AL., *supra* note 68, at 15.

Figure 2: Monash Microgrid Stakeholders[73]



To support this trend, the Australian federal government has created funds for microgrid development, such as the Regional and Remote Communities Reliability Fund, totaling AUD $20 million.[74] The fund is composed of federal government grants for regional and remote communities for power supply projects with the goal of reducing electricity costs for local residents while boosting resilience.[75] The Victorian Government is also investing AUD $10 million in demonstration projects across the state, with Monash University being one recipient in this program.[76] The devastating 2020 fire season added urgency to this government drive, demonstrating the benefits of localized power generation

73. *Id.* at 28 (listing numerous relevant stakeholders and regulators, such as the Australian Essential Services Commission).

74. *Regional and Remote Communities Reliability Fund*, AUSTRALIAN GOV'T DEP'T INDUS. SCI. ENERGY RES., https://www.energy.gov.au/government-priorities/energy-programs/regional-and-remote-communities-reliability-fund (last visited Mar. 11, 2021).

75. Mike Foley, *Electrifying Opportunities for Small Town Micro-Grids*, FARM ONLINE NAT'L (Oct. 12, 2019, 4:00 AM), https://www.farmonline.com.au/story/6433231/electrifying-opportunities-for-small-town-micro-grids/ [https://perma.cc/HN2V-4ND2].

76. *Microgrids*, VICT. STATE GOV'T, https://www.energy.vic.gov.au/microgrids [https://perma.cc/XNK8-4ZTX] (Feb. 25, 2021).

as opposed to bulk distribution systems that are more susceptible to natural disasters.[77]

Australia also has multiple start-ups focused on blockchain microgrids, with Power Ledger being among the biggest players to date. Power Ledger aims to provide cheap, clean energy by setting up microgrids linked to clean energy producers and new residential developments.[78] In so doing, it uses two blockchain layers, POWR and Sparkz.[79] POWR tokens are tradable on the public Ethereum blockchain, whereas POWR tokens may then be converted to SPARKZ, Power Ledger's native cryptocurrency, and used for electricity on the company's private blockchain.[80] The start-up recently purchased a 250-kilowatt photovoltaic system that will use blockchain-based data management, hopefully removing any potential errors in under- or over-accounting for revenue.[81]

In one trial, Power Ledger demonstrated significant potential for energy bill savings for PV producers.[82] PV prosumers typically earn 7c/kWh when exporting excess power back to the main grid, while consumers are charged 25c/kWh.[83] Power Ledger's P2P pilot project set prices to 20c/kWh of energy purchased through the platform; seventy-five percent of electricity charges went to prosumers, and twenty-five percent went to the utility company.[84] The firm has more pilot projects in several countries such as Tasmania, India, and Lichtenstein.[85] Other Australian firms focused on blockchain microgrids include Assetron Energy, Yates Energy Service, and Divvi.[86] All of these firms use Ethereum as their platform, but none have seen continued success like Power Ledger.[87]

Implementation remains a key challenge across Australia's microgrids. Questions regarding who owns these assets, how to integrate them with the existing energy market, and who is best placed to operate them are all questions that remain unresolved.[88] Further pilot tests are needed to address these challenges and in so doing power Australia's blockchain microgrid ecosystem.

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77. Jason Deign, *Australia's Fire-Hit Grid Braces for an Even Bigger Threat*, GREEN TECH MEDIA (Jan. 16, 2020), https://www.greentechmedia.com/articles/read/australias-fire-hit-grid-braces-for-an-even-bigger-threat [https://perma.cc/TM2A-HAY7].

78. James Ellsmoor, *Meet 5 Companies Spearheading Blockchain for Renewable Energy*, FORBES (Apr. 27, 2019, 2:00 PM), https://www.forbes.com/sites/jamesellsmoor/2019/04/27/meet-5-companies-spearheading-blockchain-for-renewable-energy/#1b2b2c55f2ae [https://perma.cc/EXN8-LVS6].

79. *Id.*

80. POWER LEDGER, https://www.powerledger.io [https://perma.cc/6DDJ-ZUDU].

81. Ana Alexandre, *Power Ledger Integrates Blockchain-Based Energy Auditing in Solar Power Asset*, COINTELEGRAPH (Jan. 13, 2020), https://cointelegraph.com/news/power-ledger-integrates-blockchain-based-energy-auditing-in-solar-power-asset [https://perma.cc/6DDJ-ZUDU].

82. *Id.*

83. *Id.*

84. Merlinda Andoni et al., *Blockchain Technology in the Energy Sector: A Systematic Review of Challenges and Opportunities*, 100 RENEWABLE & SUSTAINABLE ENERGY REVS. 143, 161 (2019).

85. *Id.* at 162.

86. *Id.*

87. *Id.* at 145, 161–62 (noting Power Ledger's successes and large presence in the market).

88. Andrew Burger, *Australian Prime Minister Proposes $36M Microgrid Program*, MICROGRID KNOWLEDGE (Apr. 22, 2019), https://microgridknowledge.com/australian-microgrid-program/ [https://perma.cc/DQ2N-9CEX].

C. Switzerland

Unlike the nascent, relatively fractured regulatory environment surrounding blockchain-enabled microgrids in the United States, the EU has a more advanced regime in place, though one that is still evolving as of this writing.[89] Funded by the Swiss Federal Ministry of Energy, the 2018 Swiss Quartierstrom Lighthouse Project features a decentralized solar energy market deployed in a Swiss town named Walenstadt with thirty-seven households participating.[90]

As in Brooklyn, the Switzerland microgrid enables the selling of solar energy on a peer-to-peer basis using blockchain technology.[91] This decentralized architecture enhances the resilience of Swiss critical infrastructure, which is a related goal of the EU's Network Information Security (NIS) Directive.[92] The aim of the Swiss Quartierstrom Project is to promote sustainability by incentivizing local consumption of locally generated electricity and to incentivize homeowners to produce energy through solar panels.[93] As in Brooklyn, participants trade solar energy with each other using the blockchain distributed software system.[94]

An update of this project published in 2020 following a one-year field test found that, overall, the experience was positive for those households involved and resulted in a doubling of local solar power produced in the trial but that many "were reluctant to pay more for locally produced power."[95] The trial had worked by permitting households to "set their own purchase and sales price limits for solar power. The resulting transactions were processed automatically via a blockchain."[96] The blockchain system itself was deemed to be "highly robust" and functioned by "[t]wenty-seven prosumers acted as validator nodes to approve the transactions in the blockchain."[97] These nodes, though, represent the main limitation for scaling the microgrid further. Changes in consumer behavior were observed: "many participants said that they now use electrical appliances more when the sun is shining."[98] Over time, though, it was determined that automatic pricing was more effective, and a follow-up project is being planned to explore these issues further.[99]

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89. *See* Rafael Leal-Arcas et al., *Smart Grids in the European Union: Assessing Energy Security, Regulation & Social and Ethical Considerations*, 24 COLUM. J. EUR. L. 293, 293 (2018) (analyzing the use and development of smart grids throughout the European Union).

90. Anselma Wörner et al., *Trading Solar Energy Within the Neighborhood: Field Implementation of a Blockchain-Based Electricity Market*, 2 ENERGY INFORMATICS 1, 2 (2019).

91. *Enabling Local Peer-to-Peer Energy Markets*, UNIV. ST. GALLEN, item.unisg.ch/en/operations/iotlab/p2p-energy [https://perma.cc/G8MD-QC6R].

92. *See The Directive on Security of Network and Information Systems (NIS Directive)*, EUR. COMM'N, (Mar. 26, 2021), https://ec.europa.eu/digital-single-market/en/network-and-information-security-nis-directive [https://perma.cc/PF6D-FB57] (detailing the impact the NIS Directive will have on cybersecurity in the EU).

93. Wörner et al., *supra* note 90, at 1.

94. *Id.*

95. *'Quartierstrom'—Field Test of Switzerland's First Local Electricity Market Successfully Completed*, CISION (Feb. 6, 2020, 10:00 AM), https://www.prnewswire.com/news-releases/quartierstrom—field-test-of-switzerlands-first-local-electricity-market-successfully-completed-301000337.html [https://perma.cc/3HU6-GS3Y].

96. *Id.*

97. *Id.*

98. *Id.*

99. *Id.*

D. Summary Table

	Brooklyn	**Switzerland**	**Australia**
Date of launch	2016	2019	2019
# Customers	Brooklyn Residents	37	Connects the eastern third of the MU campus
Blockchain Technology	Tendermint Protocol, TransActive Grid Blockchain architecture, and smart meters implemented		Power Ledger / Ethereum
Blockchain Use Type	Decentralized market platform	Double auction mechanism with discriminative pricing	Decentralized market platform
Openness	Limited to residents	Limited to participants	Limited to campus
Price Signals		Real-Time	
Connection to Grid?	Physical microgrid established as a backup	Yes	No
Government Involvement	No	Yes	Yes

Openness	**Limited to residents**	**Limited to participants**	**Limited to campus**
Price Signals		Real-Time	

Connection to Grid?	Physical microgrid established as a backup	Yes	No
Government Involvement	No	Yes	Yes

IV. LAW AND POLICY CONSIDERATIONS

In this Part, we identify three areas where policymakers can help promote and improve blockchain-based microgrids: improving legal and regulatory clarity and ensuring that cybersecurity and privacy risks are minimized. The first problem stems from the fact that, across the country, both microgrids and blockchain-based systems are subject to unclear and sometimes burdensome regulations. The second and third problems stem from the fact that there is no legal framework for how customer data in blockchain-enabled microgrids must be governed. In search of solutions, we explore the utility of the California Consumer Privacy Act (CCPA) and the EU's General Data Protection Regulation (GDPR) in this context.

A. Improving Regulatory and Legal Clarity

Because blockchain-enabled microgrids are a relatively new model for power generation, distribution, and sales, there is no clear legal or regulatory framework in the United States. For microgrid operators and investors, this has created significant uncertainty and risk. Specifically, microgrid operators risk being subject to burdensome federal and state laws and regulations that were designed for large, vertically integrated power companies. In every state, myriad laws and regulations determine, for instance, who may own the infrastructure that gathers, stores, and distributes electricity. More regulations dictate how energy may be bought and sold, and by whom. There are still more rules that pertain to the design of infrastructure, including necessary cybersecurity protections. Some commentators believe that the legal uncertainty in this area has held back the widespread adoption of microgrids.[100]

At the outset, it is important to note that several states have sought to encourage the development of microgrids. New York State recently allocated $40 million in funds to a microgrid design competition run by the New York State Energy Research and Development Authority (NYSERDA).[101] California has similarly attempted to stimulate

100. *See* Larry F. Eisenstat et al., *Microgrids: A Growing Trend in Search of a Regulatory Model*, POWERGRID INT'L (May 10, 2016), https://www.power-grid.com/td/microgrids-a-growing-trend-in-search-of-a-regulatory-model/#gref [https://perma.cc/RSE7-UW7U] (noting that "many microgrid projects developed to date were viewed as one-off or demonstration projects under individual fact-specific regulatory approvals, providing little in the way of precedent or a replicable path forward for future projects").

101. Patrick L. Morand, *The Evolving Role of Microgrids*, 32 NAT'L RES. & ENV'T 27, 28 (2018).

development in this space through a $200 million microgrid grant program.[102] These are just a few examples that demonstrate that a political will exists to promote these technologies. With that in mind, we believe it's helpful to consider barriers that policymakers might remove.

States regulate the local distribution and consumer ("retail") sales of electricity. This is done through a combination of regulation and law. States typically grant a Public Utility Commission (PUC) power to regulate electrical safety standards, environmental impacts, reliability, and sales, for instance. State PUCs may have the ability to regulate the use of blockchains and smart contracts for the sale of electricity within microgrids.[103] Such regulation could take many forms, including the need to obtain a license, pay retail tariffs. Policymakers seeking to encourage the development of blockchain-based microgrids would do well to consider how difficult it is to obtain the necessary permissions.

Microgrids seeking to sell excess power to utility companies or on the wholesale market will need to navigate a complicated legal and regulatory regime. Many states have enacted laws requiring power generators to purchase electricity from consumers and businesses that generate it. These are known as "net metering laws."[104] As of early 2020, forty-seven states have some form of net metering laws (with Alabama, South Dakota, and Tennessee being the holdouts), whereas thirty-four states allow consumers to take advantage of net metering credits.[105] Many states have not accounted for microgrids in their net metering programs, often making it unclear whether a community might be permitted to sell excess power back to the grid. Meanwhile, in some states, homeowners who use electricity collected from roof-tops to power their homes will not receive market-based rates when selling power back to utility companies.[106] Again, we believe that new, more permissive policies in this area could encourage greater investments.

Turning to federal law, one of the most important federal agencies that operates on the energy sector is the Federal Energy Regulatory Commission (FERC).[107] FERC regulates interstate electricity transmission and wholesales, licenses, and inspects a variety of hydroelectric projects, sets reliability standards for high voltage interstate power lines,

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102. Press Release, California Pub. Utils. Comm'n, CPUC Adopts Strategies to Help Facilitate Commercialization of Microgrids Statewide (Jan. 14, 2021), https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M360/K370/360370887.PDF [https://perma.cc/D53B-HW6B].

103. James Gatto et al., *Considering Blockchain in the Electricity Industry*, SHEPPARD MULLIN (Nov. 9, 2018), https://www.lawoftheledger.com/2018/11/articles/blockchain/electricity-industry/ [https://perma.cc/48RE-3JED].

104. SAIC, SMART GRID LEGISLATIVE AND REGULATORY PROCEEDINGS vi (2011), https://www.eia.gov/analysis/studies/electricity/pdf/sreg_policies.pdf [https://perma.cc/R7L4-9ZFS].

105. *See* Kelly Pickerel, *Which States Offer Net Metering?*, SOLAR POWER WORLD (Mar. 27, 2020), https://www.solarpowerworldonline.com/2020/03/which-states-offer-net-metering/ [https://perma.cc/V6XV-MTL7] (detailing net metering policies in different states).

106. One such state is Indiana. Under Ind. Acts 309, passed by the Indiana Senate in 2017, net metering will be phased out over time. https://legiscan.com/IN/text/SB0309/2017 [https://perma.cc/W666-764M].

107. OFF. OF ELEC. DELIVERY & ENERGY RELIABILITY, U.S. DEP'T OF ENERGY, UNITED STATES ELECTRICITY INDUSTRY PRIMER (2015), https://www.energy.gov/sites/prod/files/2015/12/f28/united-states-electricity-industry-primer.pdf [https://perma.cc/47F4-A4XT]; *see* Wei Chen Lin & Dominic Saebeler, *Risk-Based v. Compliance-Based Utility Cybersecurity—A False Dichotomy?*, 40 ENERGY L.J. 243, 248 (2019) ("The bulk power system is subject to federal regulation through the Federal Energy Regulatory Commission (FERC).").

monitors energy markets, and performs a variety of related functions.[108] A nonprofit organization called the North American Electric Reliability Corporation (NERC) sets and monitors reliability standards.

FERC has recently sought to promote the development of distributed energy resources such as microgrids. FERC Order No. 2222, passed in the fall of 2020, seeks to "remove barriers preventing distributed energy resources [including microgrids] from competing" in the energy market.[109] The rule accomplishes this goal by allowing small-scale (1 kW to 10,000 kW) power generation facilities to store, collect, and aggregate electricity for resale.[110] As FERC's website explains,

> This rule enables DERs to participate alongside traditional resources in the regional organized wholesale markets through aggregations, opening U.S. organized wholesale markets to new sources of energy and grid services. It will help provide a variety of benefits including: lower costs for consumers through enhanced competition, more grid flexibility and resilience, and more innovation within the electric power industry.[111]

To summarize, Order 2222 directs regional grid operators (mentioned in the Introduction) to allow aggregated local sources of electricity—which may include microgrids—to participate in the wholesale electricity market. Previously, small power collectors had no seat at the table.

Order 2222 could encourage greater investments in the infrastructure that blockchain-based microgrids rely upon. As an attorney with expertise in clean energy recently explained:

> There's a lot of solar paired with storage . . . around the country, . . . and a lot of those projects might not know exactly how they're going to sell and what their monetization strategy is going to be. . . . They will probably be excited to be able to be aggregated and play in these markets.[112]

Interestingly, blockchain-based microgrids may be able to solve a problem that the designers of Order 2222 are concerned about: double-counting of energy sales. The problem arises from the fact that a small-scale power facility like a microgrid may be eligible (under Order 2222) to participate in the wholesale power market, and also may be eligible to sell power back to power plants under "net metering" plans.[113] To avoid having a DER receive double-compensation (i.e., for both a retail program and a wholesale

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108. *Id.*

109. *FERC Order No. 2222: Fact Sheet*, FED. ENERGY REGUL. COMM'N (Sept. 17, 2020), https://www.ferc.gov/media/ferc-order-no-2222-fact-sheet [https://perma.cc/4EMM-T29K] [hereinafter *FERC Order No. 2222*].

110. *Id.*

111. *Id.*

112. Keith Goldberg, *FERC Market Rule Is a Clean Energy Game-Changer*, LAW360 (Sept. 22, 2020, 8:38 PM), https://www.law360.com/articles/1312471/ferc-market-rule-is-a-clean-energy-game-changer [https://perma.cc/T7QJ-SHGJ] (quoting Scott Dunbar).

113. *See generally* Participation of Distributed Energy Resource Aggregations in Markets Operated by Regional Transmission Organizations and Independent System Operators, 85 Fed. Reg. 67, 94 (Oct. 21, 2020) (to be codified at 18 C.F.R. pt. 35) (amending FERC regulations to remove barriers to the participation of distributed energy resource aggregations in the capacity, energy, and ancillary service markets operated by RTO/ISO).

program), the Order suggests that DER aggregators should be restricted from participating in the wholesale market it makes available if the facility is already enrolled in a retail program like net metering.[114] Perhaps a more flexible rule is possible, though. As a trusted and audible record of every energy transaction, perhaps a blockchain could allow a microgrid to account not only for every transaction within its community but also for any retail or wholesale sales that the community as a whole makes with outside parties.[115]

Congress has considered, but not passed, a number of bills that would more directly address microgrids. For example, the Distributed Energy Demonstration Act of 2017 was designed to "direct the Secretary of Energy to establish demonstration grant programs related to the Smart Grid and distributed energy resource technologies that are likely dependent on its deployment."[116] The bill ultimately failed, as did the 2015 North American Energy Security and Infrastructure Act, which would have "required DOE to develop an energy security plan and to report on smart meter security concerns" along with empowering the Federal Trade Commission to create smart grid trust marks.[117]

In light of Congress's poor track record in this area, federal regulators may wish to work alongside regional grid operators in a coordinated way to ensure that Order 2222 is implemented in a way that encourages microgrid investments. If there is inadequate coordination and communication between regional grid operators, the rules developed pursuant to Order 2222 may differ greatly across the country, and may create barriers to microgrid investment and adoption.[118] Meanwhile, lawmakers, regulators, and industry may wish to examine the utility of blockchains as trusted and audible records that could help solve problems like the double-selling problem discussed above.

When viewed in light of the case studies presented in Part III of this article, we believe the current legal framework has some important gaps. But these gaps are not limited to the framework by which permission is granted to microgrids. As the next section explains, cybersecurity and privacy are two areas in need of greater legal attention. The remainder of this section discusses these issues and how policymakers might address them.

B. Security & Privacy

As has been discussed and illustrated throughout the case studies in Part III, blockchain-based deployments in the energy sector are on the rise, with expectations that they may reach $5.8 billion in total investments by 2025.[119] But while such deployments come with substantial environmental and resilience benefits, they also could pose security risks. For example, all blockchains are susceptible to the "fifty-one percent rule," meaning

114. *See FERC Order No. 2222*, *supra* note 109 (stating that, "[t]he rule also directs the grid operators to allow DERs that participate in one or more retail programs to participate in its wholesale markets and to provide multiple wholesale services, but to include any appropriate, narrowly designed restrictions necessary to avoid double counting").

115. *Id.*

116. RICHARD J. CAMPBELL, CONG. RSCH. SERV., THE SMART GRID: STATUS AND OUTLOOK 14 (2018), https://fas.org/sgp/crs/misc/R45156.pdf [https://perma.cc/8USV-VUMF].

117. *Id.*

118. *Id.*

119. *See Blockchain Microgrids Are Reshaping the Energy Sector*, POWER TECH. (Feb. 25, 2019), https://www.power-technology.com/comment/blockchain-microgrids-are-reshaping-energy-sector/ [https://perma.cc/R5HW-YAF9] (stating that blockchain investments may reach $5.8 billion by 2025).

that once a miner controls more than fifty percent of the computing power on the blockchain, they could tamper with the results.[120] This might result in tampering with the prices of peer-to-peer solar energy credits or hacking the control systems that feed into local critical infrastructure such as hospitals, resulting in potentially wide-scale impacts.

In general, and has been discussed here and elsewhere,[121] the U.S. grid is vulnerable to cyber-attacks—even more so than nations like Ukraine that have long been targets of state-sponsored cyber attackers[122]—because of the rise of Internet-connected smart grids called Supervisory Control and Data Acquisition (SCADA) networks.[123] Indeed, reports date back more than a decade of such incidents; in 2009, for example, a McAfee report found that U.S. "[c]ritical infrastructure owners and operators report that their networks and control systems are under repeated cyberattack, often by high-level adversaries [such as foreign governments]."[124] The sophistication and scale of these attacks only seem to be increasing.[125]

Blockchain may help to secure critical infrastructure generally, and the grid in particular such as "by offering another layer of protection to the sensitive and mission-critical data."[126] To take one example, Guardtime, a cybersecurity firm, has used blockchain technology to help safeguard Britain's grid in collaboration with a startup

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120. Theodore Kinni, *Tech Savvy: How Blockchains Could Transform Management*, MIT SLOAN MGMT. REV. TECH SAVVY (May 12, 2016), http://sloanreview.mit.edu/article/tech-savvy-how-blockchains-could-transform-management/?utm_source=twitter&utm_medium=social&utm_campaign=sm-direct [https://perma.cc/JT5F-YVBV].

> Now imagine the opportunities that arise from the ability to search the World Wide Ledger, a decentralized database of much of the world's structured information. Who sold which discovery to whom? At what price? Who owns this intellectual property? Who is qualified to handle this project? What medical skills does our hospital have on staff? Who performed what type of surgery with what outcomes? How many carbon credits has this company saved? Which suppliers have experience in China? What subcontractors delivered on time and on budget according to their smart contracts? The results of these queries won't be resumes, advertising links, or other pushed content; they'll be transaction histories, proven track records of individuals and enterprises, ranked perhaps by reputation score.

Id.

121. *See, e.g.*, Shackelford & Myers, *supra* note 13, at 345 (describing the double spending problem in P2P networks).

122. *See* ANDY GREENBERG, SANDWORM: A NEW ERA OF CYBERWAR AND THE HUNT FOR THE KREMLIN'S MOST DANGEROUS HACKERS 3 (2020) (warning of the dangers of cyberwarfare).

123. *See, e.g.*, DANA A. SHEA, CONG. RSCH. SERV., CRITICAL INFRASTRUCTURE: CONTROL SYSTEMS AND THE TERRORIST THREAT 1–2 (2003) (identifying vulnerabilities in critical infrastructure); Elinor Mills, *Just How Vulnerable Is the Electrical Grid?*, CNET (Apr. 10, 2009, 4:00 AM), https://www.cnet.com/news/just-how-vulnerable-is-the-electrical-grid/ [https://perma.cc/SR88-LF7M] (reporting on the myriad vulnerabilities of the U.S. to cyberattack).

124. Stewart Baker et al., *In the Crossfire: Critical Infrastructure in the Age of Cyber War*, MCAFEE 1 (2009), https://www.govexec.com/pdfs/012810j1.pdf [https://perma.cc/4GKB-JQVQ].

125. *See* Brian Barrett, *Security News This Week: An Unprecedented Cyberattack Hit US Power Utilities*, WIRED (Sept. 7, 2019), https://www.wired.com/story/power-grid-cyberattack-facebook-phone-numbers-security-news/ [https://perma.cc/WQD6-YJQ2] (describing the scale of the "first known time a cyberattack" slipped through firewall vulnerabilities to cause utility grid operation "blind spots").

126. Stefan Kendzierskyj & Hamid Jahankhani, *The Role of Blockchain in Supporting Critical National Infrastructure*, 2019 IEEE 12TH INTERNATIONAL CONF. ON GLOBAL SEC., SAFETY AND SUSTAINABILITY (ICGS3) 208, 208 (2019).

accelerator, Future Cities Catapult.[127] But given the nascent state of blockchain-enabled microgrid experiments of the types surveyed in Part III, security has so far not been a primary area of concern, though this could change as these types of collaborations scale-up meaning that they would become a ripe target for increasingly brazen attackers.[128]

The California Consumer Privacy Act (CCPA) includes at least seven distinct privacy rights including: access, portability, deletion, disclosure, easy opt-out, and a private right of action when these rights are infringed.[129]Although largely a self-regulatory statute, the law nonetheless already has made waves, with more than a half dozen states from Hawaii to New York considering similar legislation.[130] As such, it could be influential in setting benchmarks for communities seeking to build out blockchain-enabled microgrids, putting into place new transparency requirements for data controllers. Requirements for data portability, similar to those in GDPR, could likewise give consumers greater control over the data that is shared with microgrid providers, including new requirements for consent and deletion following a switch in services.

Unlike CCPA, GDPR is designed to replace the 90s-era EU Data Protection Directive; it represents an expansive regulatory regime designed to create a consistent EU-wide approach to consumer protection.[131] It features a wide array of requirements ranging from ensuring data portability and consent to mandating that firms disclose a data breach within 72 hours of becoming aware of the incident and then conduct a post mortem to ensure that a similar scenario will not recur.[132] Other requirements include the need to obtain affirmative "specific, informed, and unambiguous consent" for each type of processing done with personal data.[133] Under these rules, along with related ones around vendor management and the creation of codes of conduct, microgrid operators may need to

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127. *See* Jamie Holmes, *Blockchain for Cybersecurity: Protecting Infrastructure, Data, Telecommunications*, BTCMANAGER (Jan. 7, 2016, 18:31), https://btcmanager.com/news/tech/blockchain-for-cyber-security-protecting-infrastructure-data-telecommunications/ [https://perma.cc/U33J-5AAD] (detailing how Guardtime has helped to protect the UK's grid).

128. *See generally* GREENBERG, *supra* note 122 (describing the steps that Russia's GRU has taken to undermine confidence in critical infrastructure security around the world).

129. *See, e.g.*, Mark G. McCreary, *The California Consumer Privacy Act: What You Need to Know*, N.J. L.J. (Dec. 1, 2018, 10:00 AM), https://www.law.com/njlawjournal/2018/12/01/the-california-consumer-privacy-act-what-you-need-to-know/?slreturn=20210228140502 [https://perma.cc/KL2X-Y4KH] (describing how the CCPA affects businesses inside and outside of California).

130. Gretchen A. Ramos & Darren Abernethy, *Additional U.S. States Advance the State Privacy Legislation Trend in 2020*, 11 NAT'L L. REV (Jan. 2020), https://www.natlawreview.com/article/additional-us-states-advance-state-privacy-legislation-trend-2020 [https://perma.cc/3KGZ-RXN7]; Gary Kibel & Justin Lee, *States Are Proposing Their Own CCPA-Like Privacy Laws*, JD SUPRA (Feb. 13, 2020), https://www.jdsupra.com/legalnews/states-are-proposing-their-own-ccpa-55449/ [https://perma.cc/5WSE-JU2J]; S.B. 418, 13th Leg. (Haw. 2019), https://www.capitol.hawaii.gov/Archives/measure_indiv_Archives.aspx?billtype=SB&billnumber=418&year=2019 [https://perma.cc/HV5Y-FAF8].

131. General Data Protection Regulation, https://gdpr-info.eu [https://perma.cc/4YQT-D3PN].

132. *See, e.g.*, INT'L ASS'N OF PRIVACY PROS., THE TOP 10 OPERATIONAL RESPONSES TO THE EU'S GENERAL DATA PROTECTION REGULATION (2018) (ebook), https://iapp.org/resources/article/top-10-operational-responses-to-the-gdpr/ [https://perma.cc/HUZ8-AK2S] (outlining the requirements and proper procedures for compliance with the EU GDPR).

133. Max Read, *The E.U.'s New Privacy Laws Might Actually Create a Better Internet*, N.Y. MAG. (May 15, 2018), https://nymag.com/intelligencer/2018/05/can-gdpr-create-a-better-internet.html [https://perma.cc/X2Z2-KH7W].

designate data protection officers and fulfill these other benchmarks, laying a useful foundation for boosting cybersecurity and privacy in the microgrid.

V. CONCLUSION

This Article has analyzed a range of opportunities and governance issues pertaining to blockchain-enabled microgrids, including the utility of decentralized, resilient, and participatory networks to build resilience in the U.S. grid. However, as the case studies have helped make clear, if the promise of microgrids is to scale up to provide more than a niche application across a relatively small number of communities, policy changes will need to be made at the local, state, and federal level. For the time being, our analysis is confined to the United States, but further work can and should undertake a comparative analysis for how other jurisdictions including Australia and the EU can more effectively, and securely, utilize this technology.

A. Summary of Policy Suggestions

As Part II discussed, the electrification of homes and businesses greatly increased the quality of life for the generations of Americans. Overall, this trend marked a sharp upward trend in the quality of life.[134] However, this process did not happen by accident, nor was it realized without deep coordination at the local, state, and federal levels.[135] Effective policy interventions took years to develop, leading to successes including rural electrification even as the broader energy market has now remained static for decades.[136] The advent of smart grids powered by renewable energy and blockchain technologies is starting to change that. Now, it is a back-to-the-future moment in the nation's energy system when long-running trends of consolidation and centralization are reversing to a more decentralized model.

As has been discussed in detail, the allure of decentralization is easy to appreciate especially given the well-documented failings of centralized systems.[137] They promise improved resilience from a range of disasters, both natural and potentially fueled by climate change, and artificial in the form of cyber-attacks.[138] These case studies also reveal

134. Hans Rosling measured this convincingly in his book, *Factfulness*. HANS ROSLING, FACTFULNESS: TEN REASONS WE'RE WRONG ABOUT THE WORLD—AND WHY THINGS ARE BETTER THAN YOU THINK (2018).

135. *See, e.g.*, DAVID P. TUTTLE ET AL., UNIV. TEX. ENERGY INST., *THE HISTORY AND EVOLUTION OF THE U.S. ELECTRICITY INDUSTRY*, (2016), http://sites.utexas.edu/energyinstitute/files/2016/09/UTAustin_FCe_History_2016.pdf [https://perma.cc/4YZF-UF9N] (detailing the history and structure of the electricity industry over the past century in the United States).

136. *Id.* at i.

137. In human systems, and even in the world of nature, there are many examples of centralized authorities, institutions, or resources triggering cascading failures. A famous example is Nepal, which nationalized its forests in 1957 due to a high deforestation rate. But rather than stopping deforestation, the move actually accelerated it since villagers who lost control of local resources decided that short-term economic gain was more important than long-term management. *See* J.E.M. Arnold & J. Gabriel Campbell, *Collective Management of Hill Forests in Nepal: The Community Forestry Development Project*, *in* NAT'L RSCH. COUNCIL, PROC. CONF. COMMON PROP. RESOURCE MGMT. 425–54 (1986).

138. *See* TUTTLE ET AL., *supra* note 135, at 15 ("Solar PV is a technology that brings back the initial concept of neighborhood dc power, but its integration can now be made even more robust by overlaying a dc microgrid with the existing ac transmission and distribution grid for those customers with the most demanding reliability

something important: the systems that deliver electricity into our homes and businesses are not merely technological and industrial; they are cultural, economic, and legal.[139]

Rather than one-size-fits-all policy responses to enable blockchain-based microgrids, it seems more appropriate to develop a federal framework in which community-based polycentric action may flourish. For example, the U.S. Department of Energy could follow the lead of Switzerland and the Victorian government by investing in demonstration projects such as the one described in Part IV at Monash University to identify systemic problems. The U.S. government could also offer more grant opportunities to universities studying blockchain-enabled microgrids, and potentially empower NIST to create a set of common microgrid standards to ease communication and promote interoperability. Bug bounty programs could also be created rewarding those who identify vulnerabilities in the code undergirding microgrids, and the grid more generally, along with a deeper focus by the Electricity Information Sharing and Analysis Center (E-ISAC) on smart microgrid issues. More broadly, it will be important to delineate areas of responsibility between microgrid communities, utilities, and the Department of Homeland Security, given that the grid is a core critical infrastructure but one being run increasingly through private, decentralized means.

B. Research Agenda for Blockchain-Enabled Microgrids

This symposium contribution merely scratches the surface of the many legal, governance, and technical challenges that smart microgrids present. Deeper analysis is needed not only on comparative case studies but also on the privacy and intellectual property implications of this technology. One important question relates to energy consumption. As mentioned in the introduction, large public blockchains such as the Bitcoin network have caused widespread concern because they consume massive amounts of electricity. Because much of this electricity is generated by traditional power sources, Bitcoin is believed to contribute significantly to atmospheric carbon dioxide.[140] As of this writing, it is unknown how much electricity the blockchain networks in our case studies consume. Thus, a careful empirical analysis of the net impact of these types of blockchains on carbon emissions would be helpful to regulators and policymakers. Turning to governance, more research is needed to better draw lessons from the field of polycentric governance, and the relevance of common governance tools such as the Ostrom design principles, Institutional Analysis and Development (IAD), the Social-Ecological Systems (SES), and the Governing Knowledge Commons (GKC) Frameworks to this area.

The power grid of the future will undoubtedly be larger and more complex than the grid we live with today. It will also be likely be shaped by a technological and social push for decentralization and nested governance. Realizing the benefits of this movement—i.e., a more resilient grid that will better mitigate and manage the impacts of climate change—will require the dedicated attention of academics, civil society, technology firms, power companies, and policymakers. In this way, community by community, block by block, we

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requirements.”).

139. *See* BAKKE, *supra* note 4, at 271 (describing the intricacies of electrical systems).

140. Andrew Ross Sorkin, *Bitcoin Climate Problem*, N.Y. TIMES: DEALBOOK (Mar. 9, 2021), https://www.nytimes.com/2021/03/09/business/dealbook/bitcoin-climate-change.html [https://perma.cc/4DVA-UGRT].

may be able to build a more resilient and brighter future.