



ENERGY FUTURES
— INITIATIVE —

POLICY PAPER

Promising Blockchain Applications for Energy: Separating the Signal from the Noise

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PROMISING BLOCKCHAIN APPLICATIONS FOR ENERGY: SEPARATING THE SIGNAL FROM THE NOISE

Advances in digital technologies are unlocking new opportunities for businesses in every industry. Roughly 7.5 million digital devices come online each day, changing the way people and businesses communicate and collaborate around the world. Cloud computing has grown at breakneck speed, resulting in remarkable levels of operational scalability for firms of all sizes. And recent developments in artificial intelligence, enabled by digitalization, are already disrupting how we think about transportation, medicine, energy, and other critical sectors.

Blockchain is part of this revolution – a high-value data management/transaction platform that is made possible by this increasingly digital economy. Its value to energy systems and some key energy applications are the focus of this analysis.

Energy sector stakeholders are managing a range of rapid changes: the need for deep decarbonization, flat or declining demand, integrating variable generation technologies, evolving measures of reliability, increasing customer choice, and the growing national security implications of electricity reliance. These changes are difficult for commodity-based, highly regulated energy systems with complex, extensive supply chains, and long-lived, expensive infrastructures. It is important that a range of breakthrough technology innovations in the energy sector – including blockchain applications – be explored, tested and deployed across the energy value chain. New blockchain applications for energy may assist energy players in managing these and other changes – at the same time, these applications may signal even greater changes to come, enabling new entrants and functions that could have disruptive potential.

It is important, as energy applications of blockchain are developed and deployed, to separate the “signal from the noise”. This report does this first by identifying the unique features of blockchain relative to current systems – a broad description of features that are inherent in all uses of blockchain. It then analyzes energy applications based on two basic questions: Does the application adequately align the core benefits of blockchain with the emerging issues in the energy sector? And, is the blockchain used to support an ecosystem of business or sector functions rather than a single-use?

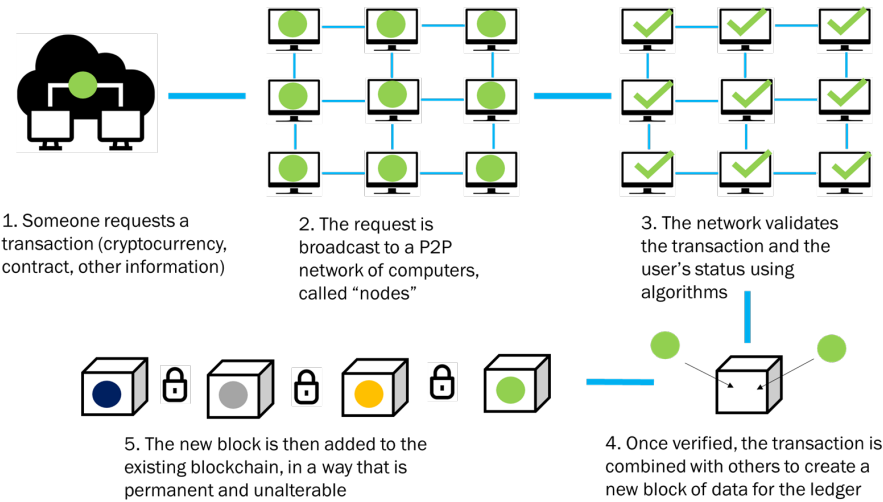
While some of the energy applications of blockchain are expected to mature over the next few years,¹ others are long-term prospects that may be limited by existing policy, regulations, business models, and systems engineering. The timing of these changes is beyond the scope of this analysis, as is the full range of applications for energy. The analysis instead focuses on five key areas – distributed energy resources, electric vehicles, energy trading platforms, carbon registries, and transactions in emerging markets – where blockchain presents significant opportunities for process improvements, added value, enhancing transparency, and improving trust between actors in the energy system.

¹ <https://www.indigoadvisorygroup.com/blockchain>

WHAT IS BLOCKCHAIN?

Blockchain is, simply put, an electronic ledger system managed without a central authority by a distributed network of independent computers, called “nodes” (Figure 1). At their most basic level, blockchains enable users to record digital transactions without risk of third-party interference or alteration.² New transactions are submitted to a node, which then alerts the network of computers of the pending transaction. A node is randomly selected to review the details of the pending transaction and determine its legitimacy using rules established by the blockchain’s design. To maximize efficiency, many transactions are bundled together by nodes into a block and are then added to the chain. All nodes receive an updated copy of the blockchain and there exists no “master” version.

Figure 1.
How Does Blockchain Work?



Adding new transactions to the blockchain is a relatively straightforward interaction between independent computers that verify each transaction and then add them to the immutable chain

Other sources: Blockgeeks, Nounproject

Any attempt to corrupt one version of the blockchain or add transactions without following the rules – failing what is essentially the digital fingerprint test – will be rejected by the rest of the network. In the same way that information on the Internet cannot be erased by destroying one computer, a blockchain’s data cannot be compromised by attacking one copy of the blockchain. This creates an intrinsic form of cybersecurity without the need for a single, centralized controller.

² <https://csrc.nist.gov/CSRC/media/Publications/nistir/8202/draft/documents/nistir8202-draft.pdf>

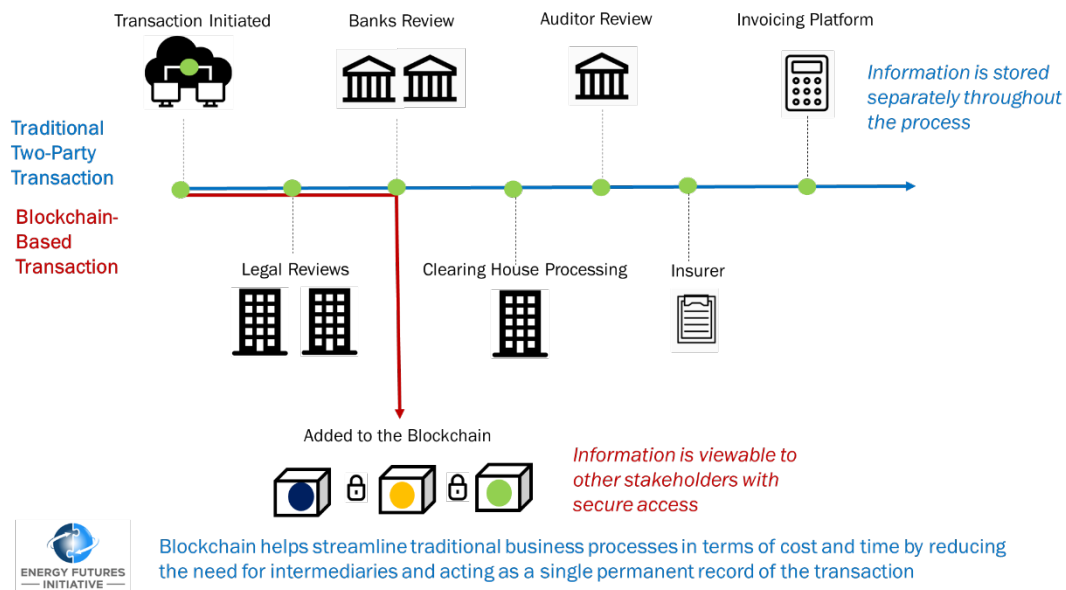
It is important to note that while blockchain guarantees the security and validity of an entire dataset, it does not attempt to review or verify the accuracy of the underlying information of the transaction. Blockchain does not alter the long-sustained mantra of data scientists, “garbage in, garbage out”; in some cases it may exacerbate the problem because of the difficulty of changing information once it is added to the blockchain. However, there is a significant amount of work being done to address this challenge.³

How Does Blockchain Add Value?

Blockchain is an approach for managing large volumes of transactions, settled quickly, securely and at relatively low cost. While many possible uses have been suggested,⁴ the real breakthrough potential of blockchain emerges from the myriad ways it can help firms capture more value from the digital economy by improving existing business processes (Figure 2). There is enormous value in the “democratization” of data through standardization and collaboration between third parties – the enabler of a cross-cutting ecosystem of information, shared by a range of disparate but connected parties.

Figure 2.

How Does Blockchain Compare to Conventional Business Transactions?⁵



A critical element to the value of blockchain is the ability to reduce multi-party transaction times to near-zero. It also dramatically reduces overhead costs of using intermediaries, such as clearing houses, enabling leaner, more profitable enterprise.

³ <https://www.research.ibm.com/5-in-5/crypto-anchors-and-blockchain/>

⁴ <https://www.wired.com/story/187-things-the-blockchain-is-supposed-to-fix/>

⁵ <http://resourcecenter.smartgrid.ieee.org/sg/product/education/SGWEB0063>; <https://thenounproject.com/>

Finally – and an extremely difficult task – blockchain can greatly improve confidence in transactions between firms and people in the digital world that can, in turn, reduce redundancies and associated bureaucracies.⁶ Blockchain-enabled systems provide businesses with a tool to manage transactions; maintain their economic advantages, privacy, and security; and reduce the costs of each. Table 1 shows a detailed comparison of blockchain with many of the standard data management approaches used by firms across the world.

Table 1. Advantages of Blockchain Over Current Data Management Approaches		
Attribute	Current Approaches	Blockchain Benefits
Database Architecture	Centralized Systems, Often Administered by Third-Party; Largely Fixed Architecture; Independent Data Taxonomies	Decentralized Systems can be Self-Administered; Scalable Design with High-Level of Flexibility; Single Data Structure
Data Permissions	Access Controlled by IT Administrator or Managed Service Provider; Policy and Architectures Limit Access of Outside Businesses Partners, Collaborators	Architecture Sets Permissions, Regulated by Rules-based System; Businesses Partners (e.g. supply chain vendors) can Access Records
Cybersecurity	Cybersecurity Protections (e.g. monitoring, digital signatures) are Add-ons to Basic Architecture; High Reliance on Human Element for Data Protection; Few Protections from Attack Vectors Using Legitimate Credentials	Cybersecurity Protections are Inherent to Blockchain Design and Layered; Advanced Cryptography Underpins Framework; Data Stored on Verifiable, Decentralized Network; Engineered to be Immutable
Contracts and Financial Transactions	Contracts and Transactions Handled Internally (or Contracted); Rules and Terms May Adapt Based on Contract Type; Highly Reliant on Trusted Third-Parties; Low Process Transparency, Enforceability, Limiting Access to Emerging Markets; Highly Centralized Infrastructure for Transactions	Enables "Smart" Contracts for Streamlining and Automating Contract Terms (i.e. Deposits, Payments, Proof of Performance Actions); Removes Need for Trusted Third-Parties; Regulators and Governments Can Observe or Record Details; High Process Transparency and Enforceability, Opening Access to Emerging Markets
Financing	Separately Managed Electronic Funds Transfers; Third-Parties Handle and Process Transactions	Supports Digital Payments; Enables Cryptocurrencies, Removing Need for Trusted Third-Parties; Cryptocurrencies Create Additional Opportunities to Capture Value (ICOs and Coin Valuation)

Source: Energy Futures Initiative

Blockchains were originally designed to support sectors that did not involve the physical exchange of goods, such as banking and finance.⁷ While blockchains do not directly engage the physical world, applications have emerged that use blockchain to optimize the processes behind physical exchanges. Commodity trades are heavily dependent on the manual exchange

⁶ <https://www.youtube.com/watch?v=JNeNQ2W15b0>

⁷ NERA and eurelectric, "Blockchain in Electricity: A Call for Policy and Regulatory Oversight"

of data and third-parties to clear and process transactions. Agricultural commodities trader, Louis Dreyfus, for example, tested blockchain for managing the sale of U.S. soybeans to China.

Blockchain has also been used to remove the intermediaries, monitor the operation in real-time, verify the data, and reduce risk of fraud.⁸ Maersk, IBM, Dutch customs, and the U.S. Department of Homeland Security used blockchain for freight trading and tracking to reduce transaction costs, lower the risk of inaccurately labeled cargoes, and optimize trade flows by managing data from across the fleet on available ship carrying capacity.⁹

Blockchain in the Boardroom

Even though the technology is available to create and sustain a range of business-enhancing platforms, the data are often not measured, captured, communicated and transacted in the most efficient ways possible. Blockchain was created, in large part, to help solve the problem of unlocking the value of data that are otherwise “left on the table” in the increasingly digital world. It does this by streamlining current approaches for business-to-business and peer-to-peer transactions. The result is significantly lower transactions costs, new incentives for additional data mining, and additional cross-industry opportunities.

Unfortunately, blockchain is sometimes treated in marketing materials, news stories and some research papers as a panacea.

This has caught the attention of the business world. Discussions of the values of blockchain have become pervasive in boardrooms in the U.S. and around the world. A survey of 308 executives from large U.S. firms revealed that more than one-quarter of them viewed blockchain as belonging in the “top-five priority” category for board consideration.¹⁰ Mentions of blockchain and digital currencies on corporate earnings calls doubled between 2016 to 2017.¹¹ This boardroom prioritization is translating into expenditures. Corporate spending on blockchain is experiencing rapid growth, expected to reach \$2.1 billion in 2018, up from \$950 million in 2017. By 2021, the global blockchain market is expected to grow to \$8.1 billion.

Unfortunately, blockchain is sometimes treated in marketing materials, news stories, and even some research papers as a panacea for whatever ails businesses in the digital world. While the attention has led to positive developments, it has also made it difficult to identify the most promising blockchain applications and the specific opportunities that blockchain helps to unlock. What is certain is that the creation of blockchain is a technology innovation. What has yet to be seen is the type and level of innovation that blockchain will cause in the energy sector.

⁸ <https://www.ft.com/content/22b2ac1e-fd1a-11e7-a492-2c9be7f3120a>

⁹ <http://fortune.com/2017/03/05/maersk-tests-blockchain-based-freight-tracking/>

¹⁰ <https://www2.deloitte.com/us/en/pages/about-deloitte/articles/innovation-blockchain-survey.html>

¹¹ <http://fortune.com/2017/11/20/ceos-bitcoin-ethereum-blockchain-cryptocurrency/>

Blockchain is not Bitcoin

Blockchain was first introduced in 2009 by Satoshi Nakamoto to improve the speed, security, cost, and trustworthiness of Internet commerce by removing the financial institutions required to process each transaction. Nakamoto proposed Bitcoin, an electronic payment system based on evidence that a user spent a certain amount of money, by performing a certain amount of computer processing, to enable any two parties to transact directly online without the need for a third party.¹²

Like any first of its kind, Bitcoin has provided major lessons learned that have already led to more advanced blockchains. Lesson One: Bitcoin is extremely energy intensive. The difficulty of the cryptographic proof increases as the blockchain grows; this is inherent to the blockchain structure of a Proof of Work (PoW) system.

Using alternative cryptography, blockchains are now being developed to be less energy intensive. One approach is called PBFT (practical byzantine fault tolerance algorithm), with the goal of requiring consensus from the entire network of users for each proposed change, rather than rewarding CPU processes.¹³ Another popular option is called a Proof of Stake (PoS) system, which randomly assigns the responsibility of reviewing each change to a subgroup of nodes that have the largest “stakes” in the network. This design is less stringent than PoW and still offers high levels of security while being vastly less energy intensive. Also, blockchains are being designed with cryptography that links to external databases that are more efficient to scale, and the blockchains manage and protect a digital representation of the data. This adds an additional step, as the underlying data must be corroborated by the blockchain’s code, which is known to be accurate. However, for larger operations this significantly reduces operational costs.

A second major lesson from Bitcoin comes from its design as a peer-to-peer electronic payment system that is free to anyone and completely transparent. This type of platform may be difficult for firms to capitalize on; private blockchains are being developed to support enterprise-wide applications for permissioned networks. A hybrid approach that combines multiple firms across a marketplace with industry-tailored designs offer many benefits in terms of operational efficiency, scalability, and cost-effectiveness.

A third major lesson from Bitcoin is that the blockchain is too powerful to be single-use only. While private firms, governments, security agencies, and other organizations desire to make online transactions faster, more reliable, and more secure, shared and stored information for such transactions may vary across user groups. To address this issue, generic blockchains or “general purpose” systems are being rapidly developed. The custom-built Ethereum blockchain is the most well-know of these platforms, enabling developers to create markets, store registries, move funds, and design many other types of applications.¹⁴

¹² <https://bitcoin.org/bitcoin.pdf>

¹³ <https://medium.com/@chrshmmmr/consensus-in-blockchain-systems-in-short-691fc7d1fefe>

¹⁴ <https://www.ethereum.org/>

BLOCKCHAIN AND THE ENERGY SECTOR

Many of the same digitalization trends that are unlocking blockchain's potential are driving profound changes in the energy sector. The rapidly growing capabilities and falling costs of digital technologies are creating energy systems that are more digitally enabled, have growing options for decentralization, give consumers greater input and control, and are less resource- and more technology-dependent. Low-cost computers and networking systems have helped drive the proliferation of smart energy devices and distributed energy resources (e.g. solar PV, demand-response, etc.) that consume and produce energy in a much more dynamic and system-responsive way. The lines between energy IT and OT systems continue to blur, creating operational complexities, demand for systems to manage these changes, and new opportunities for tools that help manage both.

The increased adoption of distributed generation, energy storage, and other smart devices are working in concert to create new complexities and challenges for operations and energy markets that are designed for centralized control.¹⁵ These and other energy sector trends are also most likely to benefit from technologies, like blockchain, that seek to optimize the use of information in order to save time, reduce cost and risk, and increase trust. Blockchain offers firms a potential pathway to better manage these changes by optimizing the use of the ever-growing amounts of energy data and creating new ways for firms and people to transact.

There are substantial public, security, and national interests in the energy sector. As blockchain applications for energy are considered, it is important to fully assess the opportunities and challenges posed by this new, innovative technology. These include the integrity of information on a blockchain, the first movers in its developments, rules of access, and requirements for transparency. These issues require appropriate attention from policymakers and regulators.

Energy Sector Uptake of Blockchain

While it is difficult to find comprehensive data, estimates suggest that to date, there has been \$100-300 million dollars invested in over 100 energy-sector blockchain applications (Figure 3).^{16,17} In the power sector, for example, global investment in digital infrastructure has grown by over 20 percent annually since 2014, reaching \$47 billion in 2016.¹⁸ According to IEA, this digital investment was nearly 40 percent higher than investment in the entire gas-fired power generation sector (\$34 billion) – and almost equal to total investment in India's electricity sector (\$55 billion). According to one source, there are over 70 blockchain demonstration

¹⁵ https://www.pge.com/pge_global/common/pdfs/about-pge/environment/what-we-are-doing/electric-program-investment-charge/EPIC-3-Application-PGE.pdf

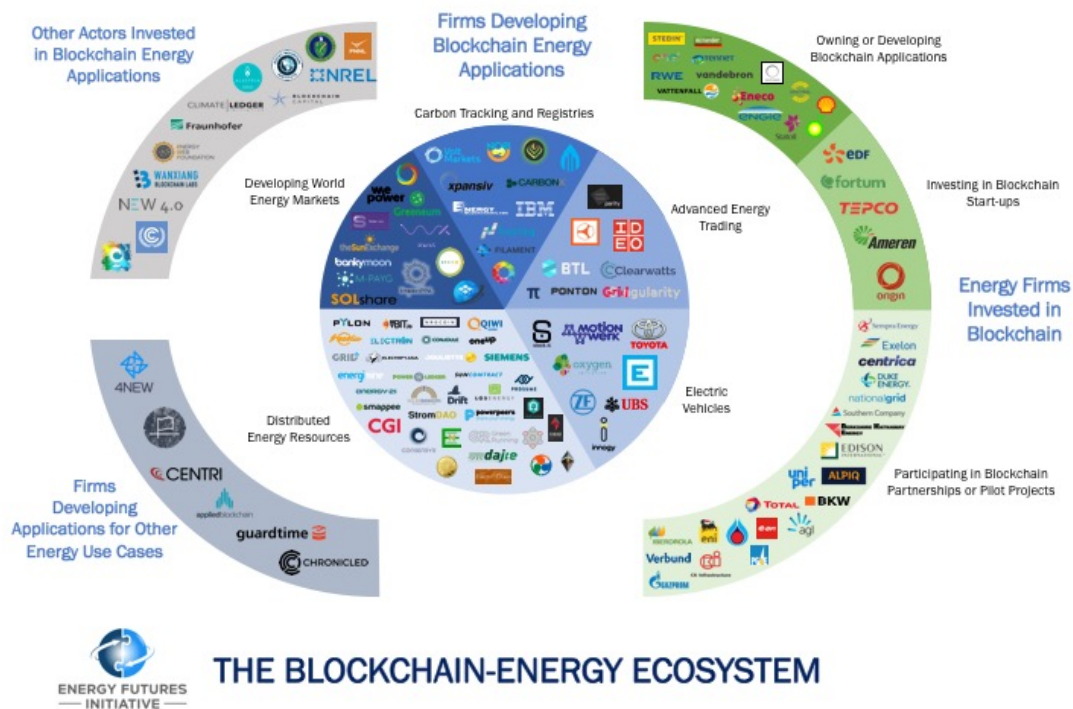
¹⁶ Author estimates based on reviews of public documents and private discussions with energy, technology, and blockchain firms

¹⁷ <https://www.greentechmedia.com/articles/read/leading-energy-blockchain-firms#gs.OHso4Ms>

¹⁸ <http://www.iea.org/digital/>

projects underway globally in electricity alone,¹⁹ while more than half of the energy executives in Germany are currently piloting or developing blockchain projects.²⁰

Figure 3.
Blockchain for the Energy Sector: An Estimated \$100-300 Million Investment



Not surprisingly, technology firms are leading the development of blockchain applications for energy. Some, like Siemens, have invested in companies that are already developing blockchains. Others are developing their own blockchain products. IBM, for example, has a dedicated “Blockchain Lab” and has been prolific in developing applications for a variety of sectors. Some of IBM’s energy-related projects include building a platform for carbon tracking in China’s cap-and-trade system, and a project working with Tennet, a European Transmission System Operator (TSO), to balance supply and demand on the high-voltage grid.

Development is not, however, limited to existing firms – at least 60 energy/blockchain focused startups have emerged in the last few years.²¹ Opportunities in the energy sector – a sector that is historically slow to change and adapt to changing market conditions – are exciting for new firms as well as for the more conventional energy players who are also getting into the blockchain

¹⁹ <https://www.greentechmedia.com/articles/read/energy-blockchain-startups-raised-324-million-since-2017#gs.wJ8CdUQ>

²⁰ <https://www.indigoadvisorygroup.com/blog/2017/3/6/global-energy-utilities-blockchain-pilots-and-use-cases>

²¹ <https://www.indigoadvisorygroup.com/blog/2017/3/6/global-energy-utilities-blockchain-pilots-and-use-cases>

business. The Energy Web Foundation (EWF), for example, is a consortium developing energy-industry standards for blockchain. It is composed of established firms like Shell, Equinor (formerly Statoil), and Japan's TEPCO, as well as over a dozen energy-blockchain startups, including Electron, Verv, and Swytch. EWF's goal is to support applications that are interoperable and may ease the transition to blockchain for other energy companies.²²

Consumers are also transforming simple energy usage into multiple, technology-enabled uses with digitalization at their core. Many customers are becoming both consumers and producers – “prosumers” who produce a share of their own energy while consuming it, often in much more efficient ways. This technology-enabled shift is forcing the reconsideration of the role of energy systems; they are being reimagined as a platform for improved service and for enabling new value streams. The smart city as envisioned offers an example: the leveraging of the vast, embedded energy system as a platform for sharing data between vehicles, office buildings, and the power grid to promote more efficient energy use.

Many customers are becoming both consumers and producers - “prosumers” who produce a share of their own energy while consuming it, often in much more efficient ways.

Finally, blockchains are important to the energy sector since they allow for broad participation in business transactions, which is crucial as firms look for new ways to unlock value from the changing system. One criterion used to evaluate the most promising applications for energy is whether a blockchain is used in an ecosystem of business functions. While blockchains exist that support information management within one firm or for limited purposes, these designs may limit the blockchain's operational scalability, utility, and value for energy systems.

Supporting Changing Energy Systems

With so many blockchain applications being developed for energy, it is important to monitor and understand the universe of possibilities and “separate the signal from the noise”. As noted, this report uses two simple criteria for selecting the most promising blockchain applications for energy: First, does the application adequately align the core benefits of blockchain with the emerging issues in the energy sector? And second, is the blockchain used to support an ecosystem of business functions rather than a single-use?

The five use cases assessed in this report are blockchain applications that support:

- Distributed energy resources (DER)
- Electric vehicle markets
- Energy trading platforms

²² <https://energyweb.org/>

- Carbon tracking and registries
- Energy transactions for emerging markets

For each use case, the core benefits of blockchain are analyzed and compared to existing or alternative solutions, and the key challenges are identified to further deployment of blockchain in each application.

Blockchain applications for energy offer the greatest breakthrough potential where there are rapid changes and emerging issues and there is alignment of energy sector trends with the core capabilities of blockchain. Table 2 highlights these trends and capabilities with the five use cases analyzed in this report.

Table 2. Alignment of Emerging Energy Issues and Core Blockchain Capabilities Result in Promising Energy Sector Applications of Blockchain		
Emerging Energy Sector Issues	Core Blockchain Capabilities	Promising Energy Sector Applications
Falling Technology Costs; Decentralization; Changing U.S. Energy Supply System; Evolving Grid Control Capabilities	Decentralized Systems can be Self-Administered; Architecture Sets Permissions, Regulated by Rules-based System	Distributed Energy Resources
Vehicle Electrification; Falling Battery Costs; Decentralization; Decarbonization	Enables "Smart" Contracts for Streamlining and Automating Contract Terms (i.e. Deposits, Payments, Proof of Performance Actions); Removes Need for Trusted Third-Parties; Regulators and Governments Can Observe or Record Details;	Electric Vehicle Deployment
Decentralization; Digitalization; Changing U.S. Supply System; Emerging Global Natural Gas Markets	Businesses Partners can Access Records; Removes Need for Trusted Third-Parties; Regulators and Governments Can Observe or Record Details;	Energy Trading
Decarbonization; Digitalization; Changing U.S. Supply System; Evolving Carbon Markets	Removes Need for Trusted Third-Parties; Regulators and Governments Can Observe or Record Details; High Process Transparency and Enforceability, Opening Access to Emerging Markets	Carbon Tracking and Registries
Global Population Growth; Shifting Global Markets; Decarbonization; Electrification	Supports Digital Payments; High Process Transparency and Enforceability, Opening Access to Emerging Markets	Energy Transactions for Emerging Markets

Source: Energy Futures Initiative

Distributed Energy Resources

Distributed energy resources (DER) are physical and virtual assets characterized by their small capacity and connection to low and medium voltage grids.²³ DERs are often behind-the-meter or connected directly to the distribution system. Examples of DERs include rooftop and community solar, electric vehicles, energy storage, and demand response. DER installations have grown rapidly in the United States in recent years, mainly due to policies aimed at higher levels of renewable energy.²⁴ While DERs have different attributes and contributions to the system, many of them can be used to increase grid flexibility, which can reduce operating costs and improve reliability.

According to the North American Electric Reliability Corporation (NERC), DERs are slowly changing how the distribution system interacts with the bulk power system.²⁵ These changes can alter the flow of power and the grid operator's response to various operating conditions. Certain types of DERs, such as community aggregated or rooftop solar, have high levels of supply variability. Since 2012, wind capacity has grown by 40 percent.²⁶ Because most DERs do not follow a dispatch signal and are generally not visible to operators, significant and unexpected DER supplies coming online can often result in high levels of system inefficiency and unnecessary cycling from other generating units (e.g. natural gas). While some grid operators can leverage advanced forecasting and create larger balancing authorities²⁷ to better respond to increases in variability, many operators do not have the infrastructure, operational practices, generation fleet, or regulatory structures to make these improvements.²⁸

Blockchain can help create a framework for improving visibility and control of DERs to meet increasingly complex grid operations needs as variable renewables and other DERs are added to the electricity system.

Blockchain can help create a framework for improving visibility and control of DERs to meet increasingly complex grid operations needs as variable renewables and other DER are added to the electricity system. The blockchain can be easily accessed by the owner of a DER (or by aggregators), facilitating DER transactions. A blockchain leveraged by DER entities, grid operators and utilities can create a trusted, secure system for managing the record, status, and transaction of the distributed resources. This benefits the grid by providing operators with critical information to enhance the situational awareness needed to manage unnecessary ramping, load forecasting, interconnection requirements as well as other primary task of

²³ https://energy.mit.edu/wp-content/uploads/2016/01/CEEPR_WP_2016-001.pdf

²⁴ http://www.analysisgroup.com/uploadedfiles/content/news_and_events/news/value_of_der_to%20d.pdf

²⁵ http://www.nerc.com/comm/Other/essntlrbltysrvcstskfrDL/Distributed_Energy_Resources_Report.pdf

²⁶ <https://www.awea.org/wind-energy-facts-at-a-glance>

²⁷ <https://www.nrel.gov/docs/fy13osti/60451.pdf>

²⁸ <https://www.nrel.gov/docs/fy13osti/60451.pdf>

ensuring reliability.²⁹ This also benefits DER owners by creating new market potential for their resources.

Also, where advanced grid controls, active market participants, and regulatory frameworks exist, “smart contracts” could be used to further increase resource efficiency. In the case of smart contracts, the blockchain is programmed with a set of conditions, so that transactions are automatically triggered when conditions are met. Smart contracts enable suppliers and consumers to automate sales by creating parameters that trigger the transaction based on price, time, and location, and, where permitting, energy resource type. In theory, these advanced applications and grid designs can create a more optimal balancing of supply and demand. TenneT, a European Transmission System Operator (TSO) in the Netherlands and Germany, for example, has partnered with IBM to pilot test blockchain for improving the performance of DER.³⁰ This project is designed to make EV batteries available to support grid balancing. TenneT sends a price signal to participating EV owners, who then record their availability and action, and transactions are handled by the blockchain. This creates a market for EV owners to sell power back to the grid, or reduce their demand, helping to create predictable loads for TenneT.³¹

Another challenge for DERs is that the benefits may be undervalued by energy markets.³² For example, DERs can support operational flexibility, helping grid operators meet daily, hourly, or sub-hourly fluctuations in supply and demand.³³ Liberalized power markets tend to focus on ensuring sufficient capacity is online to meet demand at any moment, selecting generators based on lowest marginal cost. Short-term variability is traditionally handled by a relatively small parallel market for “ancillary services”.³⁴ Market access for DERs is either unavailable, or payments are negotiated with utilities. Because utilities may be invested in existing generation capacity, and distribution systems may not be configured to properly manage these new supplies, there may be high barriers to entry for outside owners of DER.³⁵ By making transactions faster, simpler, and cheaper blockchain can contribute to better valuation of DER. With appropriate market design, blockchain can facilitate increased participation from broader market participants, including from households.

The power sector is already developing ways to make DERs more efficient and effective for the grid. A leading approach is the use of aggregators that group DER agents in a power system (i.e. consumers and producers) to act as a single entity when engaging in power markets or selling services to the operators.³⁶ Distributed Energy Resource Management Systems (DERMS) can be

²⁹ https://www.nerc.com/comm/Other/essntlrbltysrvctskfrDL/Distributed_Energy_Resources_Report.pdf

³⁰ <https://www.tennet.eu/news/detail/tennet-unlocks-distributed-flexibility-via-blockchain/>

³¹ <https://www.tennet.eu/news/detail/tennet-unlocks-distributed-flexibility-via-blockchain/>

³² https://www.energy.gov/sites/prod/files/2017/06/f34/EAC%20-%20Distributed%20Energy%20Resource%20Valuation%20and%20Integration%20-%20June%202017_1.pdf

³³ <http://energyinnovation.org/wp-content/uploads/2016/05/Grid-Flexibility-report.pdf>

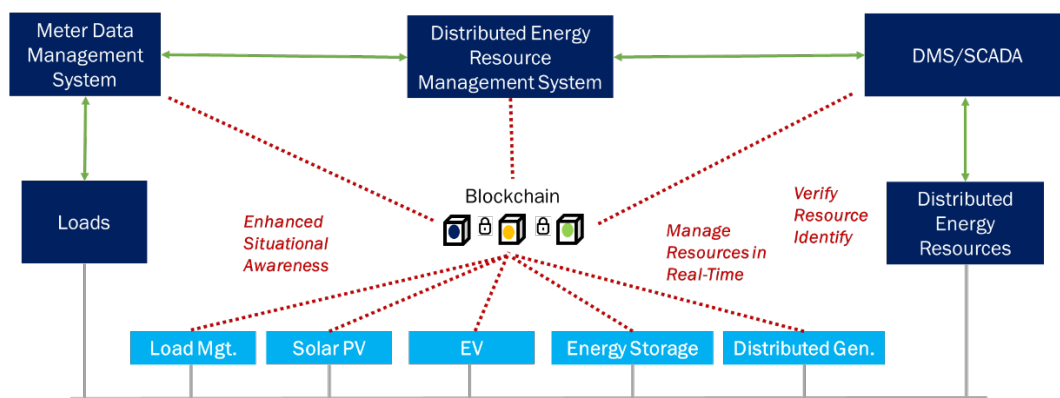
³⁴ <http://energyinnovation.org/wp-content/uploads/2016/05/Grid-Flexibility-report.pdf>

³⁵ https://ecal.berkeley.edu/pubs/CCTA17_Blockchain.pdf

³⁶ https://energy.mit.edu/wp-content/uploads/2016/01/CEEP_WP_2016-001.pdf

available to analyze load behaviors and create pathways for optimizing the benefits of these aggregated resources. Blockchain and smart contracts take this further by creating a mechanism through which individual DER entities can share their data, signal their intention, and be compensated for specific actions (or inactions) (Figure 4).³⁷

Figure 4.
Blockchain-Supported DER Management³⁸



Blockchain can be integrated into DERMS to create new mechanisms for managing DER resources in real-time with smart contracts, verifying resource identify, and enhancing situational awareness of DER entity intentions

Source: Adapted from Kley, Holger, "What is a Distributed Energy Resource Management System?"

Burlington, Vermont's municipal utility is partnering with Omega Grid to use blockchain for real-time management of supply and demand through aggregation and smart contracts.³⁹ Batteries and renewables (both forms of DER) will be managed with dynamic pricing using blockchain, while some businesses will allow for automatic curtailment in response to high prices.

In more technologically-advanced use cases, microgrids running on blockchain could enable peer-to-peer (P2P) energy markets. All members of the network could enter directly into energy exchanges without oversight from a centralized authority. The blockchain expands on the typical capacities of a P2P market through smart contracts.⁴⁰ In this market, a consumer could directly purchase energy from a desired source (e.g. solar or wind) by purchasing from a supplier of that resource. When electricity prices hit a certain level due to increased demand, a sale of power is automatically triggered between an owner of a solar PV array and a certain customer, and the microgrid only provides the wires.

³⁷ https://ecal.berkeley.edu/pubs/CCTA17_Blockchain.pdf

³⁸ <https://www.gtai.de/GTAI/Content/EN/Meta/Events/Invest/2016/Reviews/Hannover-messe/smart-grids-forum-2016-presentation-holger-kley.pdf?v=2>

³⁹ <https://www.bloomberg.com/news/articles/2018-04-09/blockchain-latest-death-knell-of-an-old-school-utility-model>

⁴⁰ <https://energy.duke.edu/sites/default/files/images/HowBlockchainandPeer-to-PeerEnergyMarketsCouldMakeDERsMoreAttractive%20%282%29%5B4%5D.pdf>

Challenges for Blockchain-Enabled DER

As DER capabilities continue to grow, they increasingly have the potential to deliver new services enabled by their distributed nature.

One challenge for blockchain for DER is that it could further complicate the ongoing debate between regulators and policymakers on its role and value. DER is already challenging many of the existing utility business models as these relatively small systems can be used together to reduce the need for traditional generation. New independent aggregators are growing in U.S. markets, in some instances forcing the redesign of markets to ensure proper access for and valuation of DER.⁴¹ Blockchain could fundamentally change certain aspects of power markets and contribute to the further shrinking of utility rate bases. New regulations, policies, and business models may be required to support blockchain's integration into systems while ensuring universal access to electricity.

Another challenge for blockchain-based DER is that many of the benefits of blockchain may only be realized in market structures with specific characteristics, including dynamic pricing, peer-to-peer offerings, and multiple organizations with shared data processes. While blockchain can help enable some of these, many power markets do not have the needed technologies (e.g. short interval smart meters), regulations (e.g. retailers with pricing flexibility), or business models (e.g. incentive to build out supply resource flexibility) to create time-of-use, peak-pricing, real-time pricing, or other structures that are enabled or enhanced with blockchain.⁴²

DER markets are in their early stage of development and may undergo significant change as they further evolve. Consequently, it may be premature to apply blockchain applications to DER, as the inherent design of blockchain makes it difficult to retroactively modify blocks in the blockchain. Once live, blockchains require significant stakeholder buy-in for large upgrades.⁴³ As DER technologies continue to improve, and costs continue to fall, they may be used to support longer-duration uses, in addition to quick response for market balancing. In 2017, AES Energy developed and deployed a 30MW battery storage unit in California, offering four hours of service for 20,000 customers.⁴⁴ A blockchain deployed today to support DER may not be structured to account for the coming changes in DER markets.

Transactive Energy in Brooklyn, NY

The Brooklyn Microgrid is a \$6 million project that leverages an Ethereum-based blockchain to manage and automate transactions over the microgrid wires between approximately 60 producers (households with DER, such as solar PV) and 500 consumers (households with smart meters) based on output levels of the DER and prices. The microgrid is connected to the Con Edison system and is designed to work together with the utility's network.

⁴¹ https://energy.mit.edu/wp-content/uploads/2016/01/CEEPR_WP_2016-001.pdf

⁴² https://www.edf.org/sites/default/files/a_primer_on_time-variant_pricing.pdf

⁴³ NERA and eurelectric, "Blockchain in Electricity: A Call for Policy and Regulatory Oversight"

⁴⁴ <https://www.energy-storage.news/news/sdgc-and-aes-complete-worlds-largest-lithium-ion-battery-facility>

Electric Vehicle Markets

The electrification of transport will play a major role in the modernization and decarbonization of energy and associated systems. The global electric vehicle (EV) stock surpassed two million in 2016 – only one year after crossing the one million vehicle mark.⁴⁵ Future growth of EVs is highly dependent on bringing down the costs and improving the performance of the vehicles, as well as more rapid charging and the availability, speed, ease-of-use, and cost of the charging infrastructure. Blockchain can support the infrastructure needed to create and build this critical market. A range of policies – from funding for RDD&D in batteries to regulatory targets, such as the Zero Emissions Vehicle Program in 10 U.S. states⁴⁶ – exists in global markets to increase the value proposition of EVs.

The availability of EV chargers remains a key barrier to market penetration.⁴⁷ In 2016, the number of electric vehicles on the road outnumbered publicly available chargers by more than six to one,⁴⁸ as most drivers rely on their own private charging systems. Estimates suggest that \$2.7 trillion will need to be invested in charging stations to enable EVs to reach their forecast potential of over half a billion vehicles by 2040.⁴⁹ There are roughly 322,000 publicly available chargers and around 1.68 million private chargers worldwide; more chargers, however, will increase certainty for drivers and add flexibility to the EV market. The predominant approach to addressing this issue is public subsidies for deployment of more chargers.

Blockchain enables and provides economic incentives for owners of private chargers to bring them online for public use. The vast majority of existing chargers deployed globally remain idle for most of the day. Blockchains are being developed to create simple, peer-to-peer transactions on private chargers so that owners can set their own prices (flat, time-based, or electricity-based) and use the blockchain to handle all billing, payment, and authentication. In most cases, a cell phone app is used to find the most convenient private charging station based on the driver's needs, such as location, cost, charging station components, etc. According to one estimate for California, with typical charging rates around \$5 per hour, a Californian could use blockchain to rent out his or her private charger enough to easily zero-out their annual EV fuel bill.⁵⁰

Blockchain's core technology – efficient and secure management of large volumes of transactions in distributed networks – coupled with the lack of a robust EV charging infrastructure and no accepted standard for billing, scheduling, and payments software make blockchain a viable solution for EVs to “leapfrog” the build-out of a massive new wires network for managing transactions.

⁴⁵ <https://www.iea.org/publications/freepublications/publication/GlobalEVO Outlook2017.pdf>

⁴⁶ <https://www.arb.ca.gov/msprog/zevprog/zevprog.htm>

⁴⁷ <https://www.iea.org/publications/freepublications/publication/GlobalEVO Outlook2017.pdf>

⁴⁸ <https://www.iea.org/publications/freepublications/publication/GlobalEVO Outlook2017.pdf>

⁴⁹ https://www.bloomberg.com/news/articles/2017-10-11/tesla-ev-network-shows-a-2-7-trillion-gap-morgan-stanley-says?cmpid=socialflow-twitter-business&utm_content=business&utm_campaign=socialflow-organic&utm_source=twitter&utm_medium=social

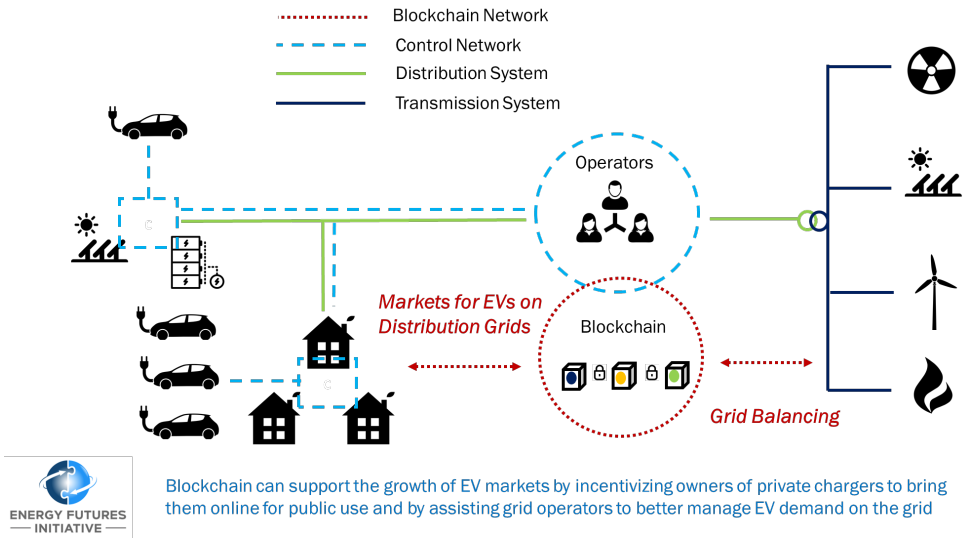
⁵⁰ <https://www.greentechmedia.com/articles/read/blockchain-enabled-electric-car-charging-california#gs.mdG0kgQ>

Germany is a world leader in supporting blockchain tools to support EV deployment. Innogy, a subsidiary of Germany’s largest utility, RWE, has already launched over 1,200 charging stations supported by blockchain.⁵¹ The owner of each station sets the price, offering flat, time-based, or electricity price-based rates. The blockchain code lives on the charging station network and is linked to customers via a smartphone app to manage and record all payment and charging data. The application, called Share&Charge, is based on the Ethereum blockchain.

ZF, UBS, Innogy, and IBM are developing a blockchain platform that automates and integrates a range of mobility services including electric car charging and billing, as well as parking fees, highway tolls, and car-sharing service fees.⁵²

Blockchain-based tools for supporting EV deployment offer unique benefits to grid operations as well (Figure 5). Current approaches use smart meters, intelligent endpoints, and behind-the-meter learning to create disaggregated load profiles.⁵³ While many of these tools rely on statistical methods, blockchain-enabled EVs offer actual load measures, providing greater certainty to operators to drive down operational costs, reduce energy use, and better target technical issues (e.g. maintenance, cyberattacks, etc.) throughout their networks. The data collected by the blockchain can help utilities and operators manage the power quality and system adequacy issues associated with the growth of EVs. The blockchain can also interact with smart meters, enhancing their role in managing information related to charger rates, locations, and usage data.

Figure 5.
Multiple Opportunities Exist for Blockchain to Support EV Charging Networks



⁵¹ <https://shareandcharge.com/en/>
⁵² <https://www.ubs.com/magazines/innovation/en/into-the-future/2017/secure-payments-on-the-go.html>
⁵³ <https://www.antennagroup.com/blog/cleantech-trends-2018>

Challenges for Blockchain-Based EV Infrastructure

There is a significant amount of hype surrounding the ability of blockchain technology to transform EV markets. Challenges to blockchain applications for EV infrastructure at the consumer, household, and local levels remain, for the widespread deployment of blockchain-based EVs.

At the consumer level, only active consumers or “prosumers” may see the full benefits from the blockchain. The additional cost of blockchain could otherwise outweigh the benefits unless consumers closely monitor the market and respond to price arbitrage opportunities to ensure a return on investment. This may require additional time and resources for consumers, which also may reduce the net benefits of blockchain.

At the household level, hosting EVs on private property may cause issues related to privacy and zoning. These could result in high barriers for the use of blockchain by owners of private charging stations who wish to offer charging services to a broader public (although this is a general problem as well). While services such as Uber, have shown that consumers are becoming more comfortable with the growth of the “sharing economy,” the location of chargers, e.g. in a garage, coupled with long charge times (minutes to hours) may limit rates of adoption. The associated security, liability, and zoning issues will likely need to be addressed at the household level.

At the local level, private charger-associated vehicle congestion at homes, offices, parking lots, or on local streets may present logistical challenges to blockchain deployment. Addressing these issues may be difficult due to their cross-jurisdictional nature. Also at the local level, blockchain offers a technology solution to improving situational awareness for distribution utilities, but this requires active engagement from the utilities themselves. Without utility buy-in, blockchain-based chargers may not be completely valued.

Advanced Energy Trading Platforms

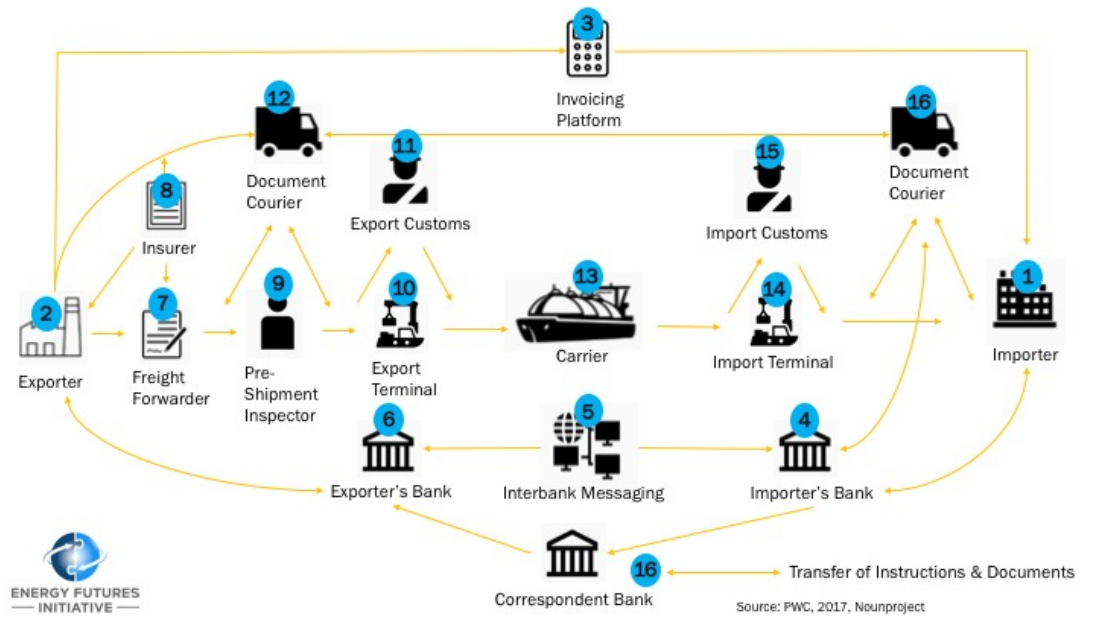
As noted, digitalization is growing across the entire energy value chain, helping firms tap into unprecedented levels of process efficiency, while reducing transaction costs and risks. Energy and commodity trading firms are increasingly relying upon the use of big data analytics and cloud-based storage to optimize their processes. Blockchain applications can build on this platform.

Even as these businesses have invested millions to automate certain processes to reduce costs, manage risks, and increase profits,⁵⁴ the trading process still heavily relies on the manual

⁵⁴ [http://www.ey.com/Publication/vwLUAssets/ey-overview-of-blockchain-for-energy-and-commodity-trading/\\$FILE/ey-overview-of-blockchain-for-energy-and-commodity-trading.pdf](http://www.ey.com/Publication/vwLUAssets/ey-overview-of-blockchain-for-energy-and-commodity-trading/$FILE/ey-overview-of-blockchain-for-energy-and-commodity-trading.pdf)

exchange of goods, multiple interactions between firms, and third-party intermediaries to close deals (Figure 6).

Figure 6.
Typical Energy Logistics Chain Requires Multiple Transfers of Documentation⁵⁵

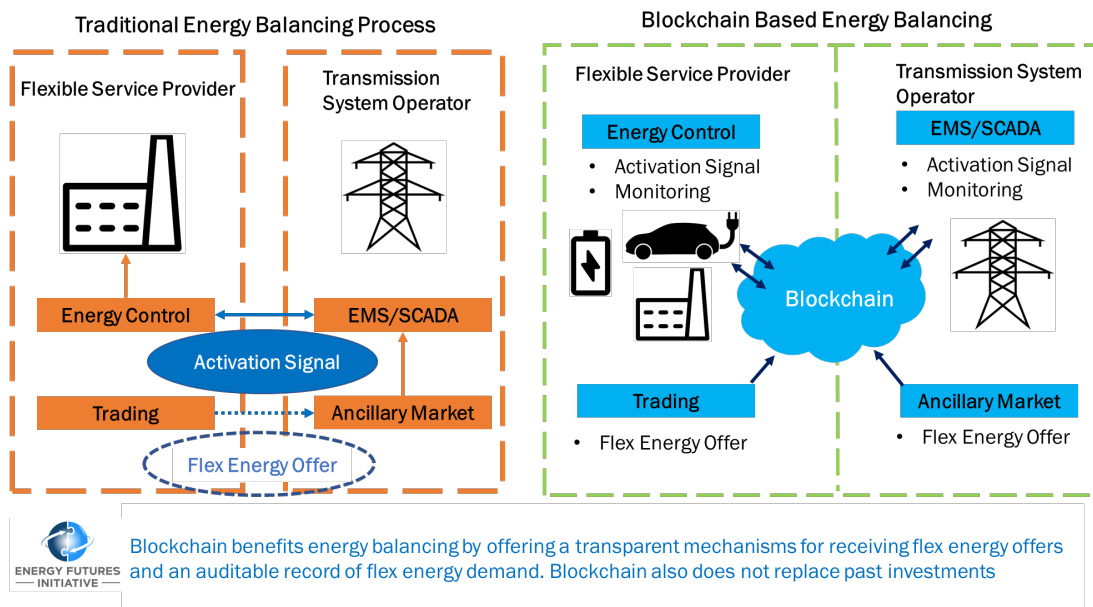


These agents may use different data tracking systems, leading to the potential for gaps or errors in information that could impede the optimization of shipping processes. Multiple parties in the supply chain purchase goods, add value, and sell goods to the next actor in the chain. The associated transfers of ownership are often still recorded on paper.⁵⁶

In wholesale electricity markets, for example, throughout a transaction lifecycle there may be clearinghouses that mitigate counterparty risk; brokers and exchanges that give market access and provide liquidity; and operations managers who book and settle deals physically and financially with counterparties and the transmission system operator (TSO) (Figure 7). A blockchain-based platform can help integrate current market participants and incentivize new ones. With smart contracts on the blockchain, more resource types, including electric vehicles, can receive payments for their active participation as sources of supply or as demand response.

⁵⁵ <https://www.pwc.com/gx/en/industries/assets/blockchain-technology-in-energy.pdf>
⁵⁶ <https://www.pwc.com/gx/en/industries/assets/blockchain-technology-in-energy.pdf>

Figure 7.
Blockchain-Based Energy Balancing Can Better Integrate the Players⁵⁷



The core benefits of blockchain are extremely well aligned with energy trading applications and the many changes related to digitalization in the energy space. Blockchain helps enable an integrated platform for analyzing big data in near real-time that could better inform trading strategies and pricing decisions. A robust trading system that leverages big data analytics could also drive the creation of a market for transactive energy, allowing firms (or consumers) to automatically settle a deal, both physically and financially. Energy trading firms could help enable these new types of markets and create rents from their applications.

Blockchain may be used to optimize the entire trading lifecycle for oil and refined products, natural gas and LNG, and electricity, from price discovery and trading to managing the back-office settlements and payments.⁵⁸ Using blockchain, transactions may be logged without the need for a single, centralized controller. This reduces or eliminates the need for multiple interactions between firms, thereby reducing labor costs, lowering capital costs through faster

⁵⁷ <http://resourcecenter.smartgrid.ieee.org/sg/product/education/SGWEB0063>

⁵⁸ [http://www.ey.com/Publication/vwLUAssets/ey-overview-of-blockchain-for-energy-and-commodity-trading/\\$FILE/ey-overview-of-blockchain-for-energy-and-commodity-trading.pdf](http://www.ey.com/Publication/vwLUAssets/ey-overview-of-blockchain-for-energy-and-commodity-trading/$FILE/ey-overview-of-blockchain-for-energy-and-commodity-trading.pdf)

settlements, and cutting technology costs by shifting away from multiple processes to a single process.⁵⁹

In addition to simplifying a firm's internal approach for managing trades, blockchain also creates a platform for sharing transaction costs between firms. Firms can split the costs of blockchain and each use it for transactions, and for recordkeeping and validation, while maintaining their data security and privacy. Energy trading is an ideal participatory network for using blockchain to help firms maintain their competitive advantage while all benefiting from increased efficiency.

Blockchain applications for energy and commodity trading are already being developed; these could have transformative impacts on process efficiency and represent significant cost savings for traders. Most of these early platforms are designed to test fully paperless trades that are standardized across data formats, business processes, and communication protocols. In early 2017, ING and Societe Generale developed and tested a blockchain with Mercuria, a global commodity trading group. The test involved an oil cargo from Africa to China, and included three different sales and traders, banks, and inspectors, all performing their role in the transaction directly on the blockchain. Digital trades using the blockchain reduced paperwork costs, risks associated with fraud and data verification, and processing times that, for banks, fell from an average of three hours to 25 minutes.

There are other pilot projects for testing blockchain applications for oil and gas trading. The Interbit blockchain was piloted by BP and Eni in June 2017 to deliver cost savings across the natural gas trade cycle. A follow-up project was announced in January 2018 that expanded to Gazprom, Eni, Total, and trading firms Mercuria and Vattenfall. EWF is also pilot testing⁶⁰ a new blockchain-enabled natural gas trading platform with partners Shell, Japan's TEPCO, and France's Engie.

The Challenges for Blockchain-Based Energy Trading

Blockchain technology has shown promising results in pilot tests for improving the process efficiency of energy trading. There are, however, challenges to widespread deployment.

Blockchain remains to be demonstrated robustly in most energy trading environments. Existing energy and commodity trading platforms represent significant investments for firms. These systems are becoming more efficient due, in part, to digitalization as firms increasingly leverage big data analysis and near real-time information.⁶¹ While blockchain offers major

⁵⁹ [http://www.ey.com/Publication/vwLUAssets/ey-overview-of-blockchain-for-energy-and-commodity-trading/\\$FILE/ey-overview-of-blockchain-for-energy-and-commodity-trading.pdf](http://www.ey.com/Publication/vwLUAssets/ey-overview-of-blockchain-for-energy-and-commodity-trading/$FILE/ey-overview-of-blockchain-for-energy-and-commodity-trading.pdf)

⁶⁰ Pilot Testing Live <http://netstats.energyweb.org/>

⁶¹ [http://www.ey.com/Publication/vwLUAssets/ey-overview-of-blockchain-for-energy-and-commodity-trading/\\$FILE/ey-overview-of-blockchain-for-energy-and-commodity-trading.pdf](http://www.ey.com/Publication/vwLUAssets/ey-overview-of-blockchain-for-energy-and-commodity-trading/$FILE/ey-overview-of-blockchain-for-energy-and-commodity-trading.pdf)

process improvements, the fully-burdened cost of a blockchain for managing a large-scale trading operation is unknown.

Existing trading systems already account for issues related to liability, which need to be clarified in blockchain-based systems. Courts are well-versed in energy and commodity trade practices and have significant experience in solving disputes involving written contracts. The regular human interaction and recordkeeping of traditional approaches offer information for the arbitrator to review. In the case of blockchain, however, there may be issues for the courts with the nature of the blockchain contract, the process for dispute settlement, and a lack of technical knowledge of the platform itself. This may be especially difficult in cases when inaccurate data are stored in the blockchain, as the distributed ledger is designed to be highly immutable. This sort of discrepancy could be difficult for courts to navigate.

Finally, as is the case for most blockchain applications, its scalability for trading depends on its interoperability across the market. In short, blockchain's utility depends on the number of active users across the system. In the case of energy trading, it may be difficult for firms to scale up their blockchain-based operations until others do the same.

Emissions Tracking and Carbon Registries

A concerted global effort is underway to decrease economy-wide greenhouse gas (GHG) emissions. Each technology and policy pathway to decarbonization will rely on methods for accurately measuring and recording carbon levels in a global marketplace with limited transparency, disconnected standards, uneven regulatory regimes, and issues of trust. Absent such tracking, progress will be highly uncertain, and goals may amount to little more than cheerleading.

A prominent mechanism for managing economy-wide carbon is an emissions trading system (ETS). An ETS establishes a mandatory cap on emissions and allocates tradeable permits to participating entities who can use them to cover their allowable emissions during a specified reporting period. An ETS is designed to restrict the overall level of emissions within a jurisdiction while creating flexibility for emitters to meet their quotas by creating a market for permits. This puts a price on carbon, establishing a pathway for companies and individuals to pursue decarbonization. Carbon credits internalize the invisible costs of everyday choices and allow a sustainable market place to emerge.⁶²

A successful ETS requires substantial resources, meticulous design, and a commitment to best practices in monitoring, reporting, and verification (MRV). The first mandatory market-based program in the United States, the Regional GHG Initiative (RGGI), for example, has previously allocated six percent of its auction proceeds for administrative expenses – \$2.4 million in 2015 alone.⁶³ Globally, there were 21 ETS in operation in 2018; and the total cost

⁶² <https://poseidon.eco/assets/documents/Poseidon-White-Paper.pdf>

⁶³ <https://www.unep.org/content/sdfinance/en/home/solutions/carbon-markets.html>

to administer these systems was an estimated \$980 million.⁶⁴ While there could be significant benefits from closer coordination across each market—these economies account for over 50 percent of global gross domestic product – each system maintains its own type of MRV and relies on different legal, accounting, and regulatory structures.

Ensuring accurate and transparent MRV is critical to creating carbon markets for deep decarbonization. Issues of accountability have been reported due to inadequate MRV, resulting in lower entry rates for some potential market participants.⁶⁵ This has likely slowed progress on emissions reductions. According to one estimate, double-counting of international offsets may lower the ambition of current mitigation pledges by 20 percent.⁶⁶

In addition to ETSs, carbon registries are key repositories for managing GHG inventories at the entity and project levels.⁶⁷ Registries may be used by entities operating in an ETS, for tax credit programs, and by carbon offset programs adopted by industries or firms.⁶⁸ Carbon registries also work to develop best practices in data collection, transparency, and harmonization with other reporting mechanisms.

In many markets, registries are required to use third-party verification to ensure accuracy, consistency, and completeness of the inventories submitted.⁶⁹ These third-party costs alone range from \$5,000 to \$500,000, depending on many factors including company size and number of sites visited.⁷⁰

Blockchain's core capabilities directly align with the many challenges around developing, deploying, and managing emissions tracking and trading systems. As a trusted repository of transaction data, blockchain can be used to streamline trades, strengthen

the verification process, and eliminate the need for costly centralized management (Figure 8).

Emissions Trading Systems Worldwide

There are 21 ETSs around the world that operate at varying levels of governance: 17 provinces and states, five countries, five cities, and one supranational institution. These economies currently represented by ETSs account for over 50 percent of global gross domestic product. At the domestic ETS level alone, 15 percent of global emissions are now covered with the recent addition of China's ETS. Looking ahead, five more ETSs have been officially scheduled (Nova Scotia, Mexico, Taiwan, Ukraine, Virginia) while 10 governments are actively considering the implementation of an ETS (Brazil, Chile, Colombia, Japan, New Jersey, Oregon, Thailand, Turkey, Vietnam, Washington).

⁶⁴ <https://www.weforum.org/agenda/2017/09/carbon-currency-blockchain-poseidon-ecosphere/>

⁶⁵ <http://www.climatefocus.com/sites/default/files/20160105%20-v.2.0%20Double%20Counting%20and%20Paris%20Agreement%20FIN.pdf.pdf>

⁶⁶ https://unfccc.int/files/bodies/awg-lca/application/pdf/20120519_can_0930.pdf

⁶⁷ https://www3.epa.gov/ttnchie1/conference/ei19/training/ghg_inventory101.pdf

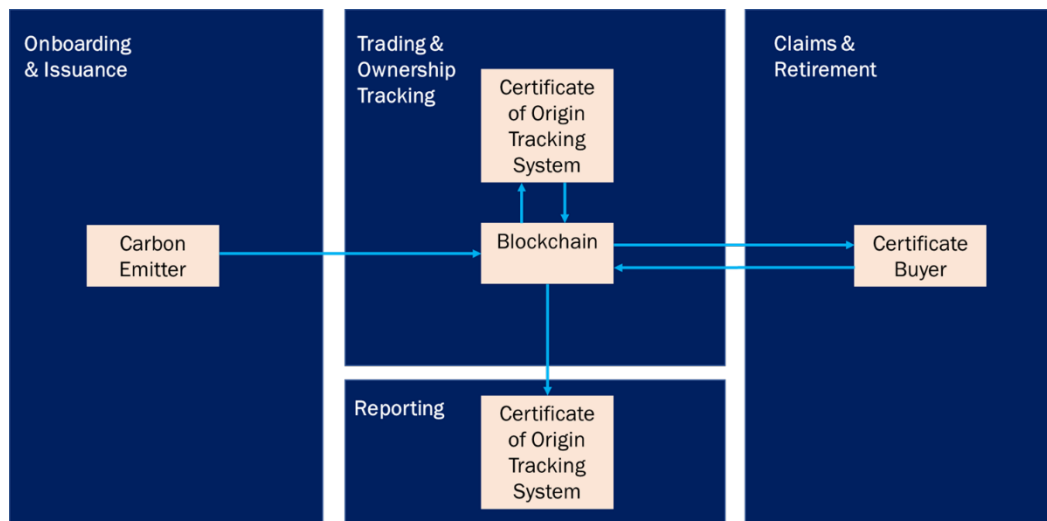
⁶⁸ <https://static.googleusercontent.com/media/www.google.com/en//green/pdfs/google-carbon-offsets.pdf>

⁶⁹ https://www3.epa.gov/ttnchie1/conference/ei19/training/ghg_inventory101.pdf

⁷⁰ https://www.c2es.org/site/assets/uploads/2001/10/emissions_verification.pdf

Blockchain could help harmonize design criteria across numerous ETSs through a uniform set of rules, maintaining a consistent framework for interoperability between linked systems.

Figure 8.
Example of Blockchain's Streamlined Process⁷¹



Source: Adapted from Energy Web Foundation



Blockchain can help address many of the current challenges facing carbon markets, including validating MRV, harmonizing market rules, and ensuring transparency of processes across members.

MRV design criteria created by market participants can be embedded in the blockchain to establish consistent markets, while assuring best practices are maintained.

Another major benefit of blockchain for carbon tracking and registries is the opportunity to create an immutable and transparent record of the market data. This could provide an accountability mechanism for mitigation efforts such as the Paris Agreement where countries are responsible for executing their Nationally Determined Contributions (NDCs) in a rigorous and transparent manner. A major impediment to increasing the transparency of the energy sector's GHG emissions has been a reported lack of clear metrics and methods for entities to track their emissions throughout the energy value chain.⁷²

Blockchain could provide clarity, credibility, and interoperability for carbon inventories and registries around the world. These blockchain benefits could also help facilitate the tracking of carbon emissions across the range of carbon capture, utilization, and storage (CCUS)

⁷¹ <https://www.oecd.org/going-digital/digital-security-in-critical-infrastructure/digital-security-workshop-february-2018-Trbovich.pdf>

⁷² <http://www.aspeninstitute.it/aspenia-online/article/blockchain-based-energy-future>

activities. Once the CO₂ has been captured from some process or removed from the atmosphere, for example, blockchain could help track any transactions involving CO₂ purchases (e.g., for enhanced oil recovery or carbon-to-value uses) or for direct geological sequestration. Such tracking could help foster markets for CO₂ while also assisting with the MRV requirements of injection sites. Nori, a newly-formed blockchain technology company in the United States, is seeking to facilitate a carbon removal marketplace where suppliers who remove CO₂ from the atmosphere can connect with buyers who want to purchase verified carbon removal certificates.⁷³ Such a platform could help provide greater value for CCUS projects, whether the CO₂ is captured from point sources or removed from the atmosphere through direct air capture. The blockchain could serve as a verification method for the captured CO₂ and facilitate the transaction between suppliers and buyers.

IBM and Energy-Blockchain Labs are testing a carbon credit management platform in China using blockchain. As China builds-out its carbon market, the blockchain application works as a carbon credit management ledger to enable carbon asset development. The platform aims to support better digital collaboration (i.e. data management), reduce transaction costs by up to 30 percent, and enable a credible carbon market, which may increase participation from new investors.⁷⁴ Increased transparency and auditability may also help regulators in China plan for the development of a nation-wide carbon trading market.

The type of architecture created by blockchain for carbon tracking and registries may also apply to managing renewable energy certificates (RECs), another type of emissions-reductions market. A REC is a market-based instrument provided to renewable energy generators based on actual and estimated levels of electricity from a renewable energy resource.⁷⁵ Similar to other emissions tracking systems, RECs have had challenges in implementation, including issues associated with trust, data accuracy, and MRV. Using blockchain with sensors and transactive energy could help reduce inaccuracies and streamline trade verification, while eliminating the need for a central agency to manage the REC market.

Greeneum offers an integrated blockchain application that serves as a shared platform for trading carbon credits and renewable energy certificates, while offering advanced analytics, including artificial intelligence, to help users better predict global renewable energy resource production.⁷⁶ Greeneum hopes to incentivize clean energy production by opening new trading markets and offering more advanced analytical capabilities to support trader decision-making. It is currently being piloted across Europe, Cyprus, Israel, the United States, and Africa.⁷⁷

⁷³ <https://nori.com>

⁷⁴ <https://www-03.ibm.com/press/us/en/pressrelease/51839.wss>

⁷⁵ <https://www.epa.gov/greenpower/renewable-energy-certificates-recs>

⁷⁶ <https://www.prnewswire.com/news-releases/english-releases/solarchange-founders-introduce-new-blockchain-based-network-for-global-decentralized-energy-trading-300539684.html>

⁷⁷ <https://www.prnewswire.com/news-releases/english-releases/solarchange-founders-introduce-new-blockchain-based-network-for-global-decentralized-energy-trading-300539684.html>

Challenges for Blockchain-Based Emissions Tracking and Registries

There are several major challenges for blockchain in emissions tracking and registries. First, it may be difficult for firms to justify the switch to blockchain as significant investments have been made in current platforms. As noted, nearly \$1 billion is required to manage current frameworks for ETSs alone, excluding the investments made by other registries to track and manage emissions data and credits. Also, blockchain remains relatively untested in emissions markets, while the fully-burdened cost of deploying blockchain in these use cases is unknown.

Another major risk is the uncertainty around the successful adoption of blockchain across the market. While blockchain is a single distributed ledger, it still requires firms to shift from their existing systems to the blockchain. Without widespread adoption, firms may need to maintain redundant systems, potentially reducing the near-term value of blockchain.

Finally, a blockchain for international carbon tracking and registries requires significant consensus from market stakeholders on the blockchain's design, its use case, and cost-sharing mechanisms for the tool itself and other support infrastructure, such as the ICT. The blockchain's design would need to be agreed to by market participants before deployment and it would likely need to run by a competent, neutral party. While many blockchains can be changed after deployment, or new copies of the blockchain can be created (called "forks"), these moves can significantly reduce the process efficiency and thus the overall benefits of using blockchain.

Energy Transactions in Emerging Markets

With half of the global population growth occurring in just nine countries – mostly in emerging markets in Asia and Africa – it will be critical to create sustainable pathways for both economic and energy sector development. This will be challenging for many countries that lack the existing infrastructure needed to enable growth or have limited institutional capacity for the management of rapid development. Pathways that can support population growth and economic development while avoiding massive infrastructure investments and build-outs will be needed to sustainably meet demand.

The deployment of decentralized energy systems, mostly solar PV, have been the most cost-effective approaches to increasing energy access rates in the last few years.⁷⁸ Massive investments in emerging markets (including China) outweigh total clean energy investments in the developed world, and have led to significant gains in energy access rates.⁷⁹ From 2000

⁷⁸ <https://webstore.iea.org/download/summary/274?fileName=English-Energy-Access-Outlook-2017-ES.pdf>

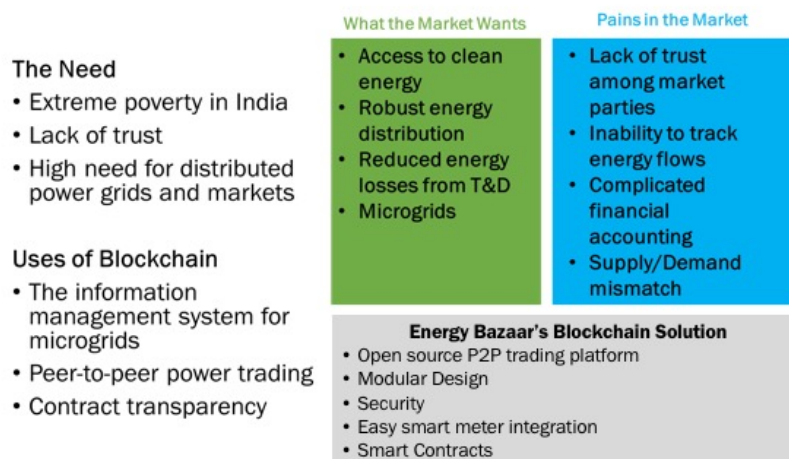
⁷⁹ <http://global-climatescope.org/en/insights/emerging-markets-investment/>

to 2015, the number of people living without access to electricity fell from 1.7 billion to 1.1 billion.⁸⁰

Many emerging economies lack the institutional capacity to build and sustain robust, traditional energy markets. Such markets can benefit customers by unlocking economies of scale (lower prices and access to more customers), ensuring long-term investment into the system, and improving operational reliability. Such institutional capacity includes mechanisms for payment and delivery between suppliers and customers, the presence of reliable arbitrators, and the transparency and credibility needed to boost investor confidence; these elements may not be embedded or available in most decentralized systems.

Blockchain offers a framework for automating many fundamental institutional capacities that are generally handled by large organizations with many employees. Blockchain creates a trusted system for handling energy transactions, including billing and settlement, and can do so without the need for a central authority (Figure 9). For rural communities, blockchain can manage information on kWh of energy that are generated and used. The transactions can be monitored and cleared without the need for third-party auditors to control smart meters and verify data. This can drastically improve ease of use for market participants, while at the same time improving trust and creating price arbitrage opportunities.

Figure 9.
The Energy Bazaar Example: Using Blockchain for Microgrids in India⁸¹



Blockchain, as a platform technology, offers many benefits to emerging energy markets that often lack the institutional capacity for reliable payment mechanisms, impartial arbitrators, and transparency and credibility

⁸⁰ <https://webstore.iea.org/download/summary/274?fileName=English-Energy-Access-Outlook-2017-ES.pdf>

⁸¹ https://docs.wixstatic.com/ugd/2f7a3c_93e0648ce597476583a130cb3972fbb7.pdf

Urban areas in emerging markets that have some of these institutional capacities also face challenges – many of them financial – for improving service to existing customers or bringing new ones online. Balancing electricity systems is challenging, even in the ideal conditions. In emerging markets, many distribution companies lack accurate and timely information on the system conditions; this can make reliable grid operations very difficult. Because many⁸² utilities operating in these environments are not creditworthy, or lack the policies needed to encourage needed investments and necessary improvements in services from the power sector may not be possible.

Blockchain can increase investor confidence to engage in markets that have had historically high risks. While there are many ways to finance projects including private equity, tax equity, renewable energy bonds, power purchase agreements, and others, firms are testing blockchain-based energy trading platforms to lower transaction costs and increase investor certainty. WePower has developed a blockchain to help renewable energy producers raise capital by issuing their own energy “tokens”. Buyers (both consumers and investors) support the development of these projects that will be governed by blockchain to simplify cross-border transactions. Producers can raise capital based on price-competitive blockchain process efficiencies. WePower is currently piloting the application with 220 Energia, an electricity retailer in the Nordic and Baltic regions⁸³ and its goal is to create renewable energy markets that run on blockchain-enabled transactions.⁸⁴

While many of these characteristics could also support the creation of EV charging markets or DER deployment, the potential for blockchain to disrupt emerging energy markets is much greater than in the developed world. In Bangladesh, for example, where 65 million people lack grid access, Solshare has developed a peer-to-peer solar electricity trading platform for homes.⁸⁵ The system includes a smart meter, solar charge controller, data analytics tools, and a blockchain to manage peer-to-peer electricity trading and mobile money payment.⁸⁶ Solshare envisions these distributed networks can drive “smart villages” as neighbors coordinate the delivery of more inclusive services and foster entrepreneurial capacity.

Technology breakthroughs over the last decade have already helped many developing world countries “leap frog” phases of development. For example, digital communication systems are being rapidly deployed in parts of Africa that never saw landlines...According to one estimate, in 2016, Africa saw the fastest uptake of mobile phones in the world and mobile subscribers are set to hit half a billion by 2020.

⁸² https://docs.wixstatic.com/ugd/2f7a3c_8fe6a1af748b41e3acf796e534808130.pdf

⁸³ <https://medium.com/wepower/how-wepowers-blockchain-based-energy-financing-will-revolutionize-traditional-financing-for-f93cf11a7145>

⁸⁴ https://drive.google.com/file/d/0B_OW_EddX05RWWFVQJGZXpQT3c/view

⁸⁵ <https://www.me-solshare.com/how-it-works/>

⁸⁶ <https://www.me-solshare.com/how-it-works/>

Monetizing excess solar by selling to another community can also unlock new financial incentives for optimal energy use.

A similar effort is underway by Energy Bazaar, a firm that is developing blockchain to support the development of microgrids in rural India, where 244 million people lack energy access.⁸⁷ A major challenge that Energy Bazaar seeks to manage with blockchain is the lack of trust in economic transactions. Rooftop solar PV deployments in India are expected to triple by 2021; it is anticipated that blockchain can provide a way to effectively trade and share electricity. The blockchain offers an easy-to-use system for automating energy exchanges, while accounting for and providing a public record for every exchange.

In key ways, blockchain can help emerging markets “leapfrog” certain analog technologies by offering a system that supports the deployment of digital ones. Technology breakthroughs over the last decade have already helped many developing world countries “leap frog” phases of development. For example, digital communication systems are being rapidly deployed in parts of Africa that never saw landlines. Digital networks allow for phone calls to be placed over the Internet while landlines require massive and costly physical single-use infrastructures to send signals through a series of exchanges that connect two phones. According to one estimate, in 2016, Africa saw the fastest uptake of mobile phones in the world and mobile subscribers are set to hit half a billion by 2020.⁸⁸

Challenges for Blockchain-Based Transactions in Emerging Markets

In emerging markets, where robust energy services do not exist, blockchain can be used as a platform for handling energy transactions, billing and settlement, and even to support investor confidence to engage in markets that are historically high risk. Challenges remain.

In some emerging markets it may be difficult to ensure active consumer participation at high levels. As noted, active energy consumers are likely to see full benefits from blockchain. In the Energy Bazaar example, blockchain can create peer-to-peer electricity trading. This is dependent on market participants who closely monitor conditions and respond to price arbitrage opportunities—which may be adjusting the smart contract terms. This may require additional time and resources to maximize a return on investment. This is challenging in the developed world but education levels in emerging markets may pose particularly high barriers to active participation at the individual consumer level.

While blockchain can help to ease the regulatory burden in emerging markets, the relatively new and untested nature of blockchain may make its adoption too risky for existing regulatory structures to adapt. While blockchain technology does not often come on a regulator’s radar, blockchain-based cryptocurrencies clouded and confused issues associated with blockchain

⁸⁷ https://docs.wixstatic.com/ugd/2f7a3c_8fe6a1af748b41e3acf796e534808130.pdf

⁸⁸ <https://fortistelecom.net/voip/voip-vs-landline-difference/>

technology. In early 2018, Chinese authorities banned cryptocurrencies and initial coin offerings (ICOs) due to their high-level of financial instability.⁸⁹ Nearly a dozen other countries in emerging markets have relatively tight restrictions on cryptocurrencies, including Indonesia,⁹⁰ Nigeria,⁹¹ and Brazil.⁹² The Central Bank of Kenya issued a public warning against the use of bitcoin in 2015, citing a lack of regulations to govern its use, and banks were also instructed to not provide services to cryptocurrency startups.⁹³ These regulatory issues may create challenging go-to-market plans for other blockchain-based technologies.

Finally, these challenges may have negative, counter-intuitive feedbacks into investor confidence. For emerging markets that lack regulatory support, clear technology standards, and clear track records for blockchain markets, there can be high risks to early adopters of blockchain-based energy systems.

Legal and Regulatory Applications of Blockchain in the Energy Sector

Energy law, regulation, and policy are additional areas where the value of blockchain can be harnessed across the energy sector. The use of blockchain for emissions tracking and carbon registries, discussed earlier, is a case-in-point. The trustworthiness and immutability of information on the blockchain could potentially help in the enforcement of climate change legislation that depends on emissions tracking.

Another area where blockchain might be useful is in regulation of energy trading. Peer-to-peer trading with DER and advanced trading among major energy firms involves transactions at vastly different scales. Advanced trading also has a firmly established legal framework governing it, whereas DER is relatively unregulated right now. However, regulation for both could benefit from the implementation of blockchain. One of the core characteristics of blockchain is that it is distributed; this would allow a regulatory authority to participate as a node on the blockchain.⁹⁴ Regulators could oversee transactions as they occur; trading could avoid the inefficiency of documentation having to pass from the transacting parties to the regulator and back again.

Energy trading regulators, both for DER and for advanced trading, could also benefit from the implementation of smart contracts. Some legal observers question whether or not smart contracts meet all legal tests of long-standing principles of contract law;⁹⁵ smart contract may, however, still be used by regulators to ensure that energy trades are conducted with uniformity and in compliance with all regulations. They may also improve process efficiency by automating certain paperwork required for trading. For example, ING has been testing a way

⁸⁹ <https://qz.com/1280458/china-now-rates-bitcoin-ethereum-and-other-cryptocurrencies-and-their-blockchain-tech/>

⁹⁰ <https://www.coindesk.com/indonesias-central-bank-cryptocurrency-payments-not-legitimate/>

⁹¹ <https://techpoint.ng/2018/04/11/cryptocurrency-nigeria-should-switch-sides/>

⁹² <http://www.latinfinance.com/magazine/2018/march-april-2018/brazil-bears-down-on-cryptocurrencies>

⁹³ <https://www.coindesk.com/kenyas-central-bank-chief-warns-crypto-risks/>

⁹⁴ <https://jenner.com/system/assets/publications/17371/original/Scarborough%20Steffen%20Law360%20Sept%2013%202017.pdf?1505423412>

⁹⁵ <http://www.osborneclarke.com/insights/an-introduction-to-blockchain-the-key-legal-issues/>

to use blockchain to digitize the “bills of lading” process for oil and gas trading, which currently depends on physical pieces of paper to execute trades.

The benefits of blockchain could also be harnessed to implement consumer protection and anti-trust law in the energy sector. All users on the blockchain have equal access to data; there is no “gatekeeper” entity.⁹⁶ This could be very useful in jurisdictions where competition is ensured by preventing energy companies from sharing data with one another. For example, blockchain could aid in the implementation of the “unbundling” requirement of the EU’s “Third Energy Package,” which requires that electricity generation companies be separated from transmission companies.⁹⁷

Legal and Regulatory Challenges for Blockchain

Blockchain faces many of the same legal issues that have previously confronted other new digital technologies, including questions about jurisdictions, risks, liabilities, intellectual property, data privacy, and enforceability of existing regulations. Some of these issues are raised by the energy use cases discussed earlier. The sharing of electric vehicle charging infrastructure on private property, for example, raises significant issues of liability and privacy. There are also issues of liability and jurisdiction with energy trading platforms, since blockchains will likely be jointly owned and involve transacting parties and nodes in several different countries.

In addition to these concerns, there are legal and regulatory issues that are specific to energy applications, especially in the electricity and gas sectors. These issues have special relevance to electric vehicles, DER, and developing world markets. Energy regulation is often constructed around clearly delineated roles, such as supplier, consumer, and transmission owner;⁹⁸ blockchain and other emerging technologies are blurring the lines between these roles. Widespread adoption of certain blockchain technologies may depend on deregulation of retail energy markets; some blockchain companies, such as the utility-scale start-up Drift, are currently confined by their business model to deregulated markets only.

The ways energy infrastructure is financed may also raise issues, especially with widespread adoption of blockchain in areas like EVs and DER. Financing for transmission and distribution networks is currently regulated so that costs are covered over the lifetime of the investment. Under a system where there are alternative methods for energy supply, costs are transferred onto customers who stay “on-grid.”⁹⁹ In the case of widespread adoption of blockchain for certain energy applications, regulations may have to change to avoid this cost shifting.

⁹⁶ <https://www.pwc.com/gx/en/industries/assets/pwc-blockchain-opportunity-for-energy-producers-and-consumers.pdf>

⁹⁷ <https://www.pwc.com/gx/en/industries/assets/pwc-blockchain-opportunity-for-energy-producers-and-consumers.pdf>

⁹⁸ <http://www.nortonrosefulbright.com/knowledge/publications/165332/blockchain-and-the-energy-sector>

⁹⁹ <http://www.nortonrosefulbright.com/knowledge/publications/165332/blockchain-and-the-energy-sector>

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ABOUT THE ENERGY FUTURES INITIATIVE

WHO WE ARE

The Energy Futures Initiative is a Washington-D.C.-based nonprofit dedicated to energy innovation under the direct management of former Energy Secretary Ernest J. Moniz.

WHAT WE DO

Led by principals with [decades of experience](#) and proven track records in government, academia and the private sector, EFI conducts objective, fact-based and rigorous technical, economic, financial and policy analyses supported by a multidisciplinary network of experts. We focus on solutions that are effective, pragmatic and acceptable to the broadest possible set of stakeholders.

STRATEGIC APPROACH

The EFI team of experts provide policymakers, industry leaders, NGOs and other leaders with analytically-based, unbiased policy options to advance a cleaner, safer, more affordable and more secure energy future. The EFI team and its global network of experts understand current energy markets, trends and needs, and will apply this collective talent and knowledge to a range of policy questions, including:

- Analyzing complex energy systems, providing public and private decision-makers with strategic insights and integrated policy solutions and politically viable implementation pathways.
- Advancing synergistic clean energy technologies and policies at home and around the world.
- Convening industry, labor, policymakers, philanthropists and NGOs to forge practical implementable climate change solutions.
- Promoting strong communities and a 21st century energy workforce, with a focus on city, state and regional innovation opportunities.

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