Managing Climate Change in the Energy Industry With Blockchains and Oracles

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Chainlink Labs

Executive Summary

The energy industry is undergoing major infrastructure and market transformations due to the growing demand for clean energy, predominantly fueled by attempts to curb the harmful effects of climate change. To facilitate the transition to clean energy, government subsidies and financial incentive programs have been introduced to drive investment into renewable energy projects and carbon capture technologies. Additionally, global climate emissions reporting frameworks have been developed to set higher international standards and enforce accountability. However, the transition to clean energy comes with a host of challenges, from persuading a diverse range of stakeholders to commit to ambitious climate change goals to meeting global energy demand while introducing less-predictable renewable energy sources to keeping inflationary pressure on energy prices down throughout the transition process.

Blockchain technology has the potential to be an important tool in supporting the necessary transition to clean energy, serving as shared, open-source backend infrastructure that enables multiple independent parties to track assets via a global ledger and enforce agreements using cryptographic truth[1]. By leveraging blockchains, the energy industry can better digitize and assign value to clean energy investments, leading to more democratized access to green investment cash flows, greater transparency into the success of clean energy projects, and stronger accountability around stakeholders meeting their stated commitments.

In order for blockchains to be able to provide this support to the energy industry, infrastructure known as oracles is required. Oracles are middleware that deliver off-chain data (e.g. energy data) on-chain (i.e. onto a blockchain), perform secure off-chain computation, and facilitate communication between different blockchains. As secure middleware, oracles allow blockchains and the smart contract applications that run on them to interact with real-world data streams and traditional backend systems. Oracles are critical to realizing blockchain-based markets for clean energy investment and management because they connect the existing energy industry to blockchains. Through oracles, a plethora of new blockchain-based use cases in clean energy can be unlocked, such as tokenized cash flows for renewable energy projects, trusted on-chain rating systems for green bonds, specialized derivatives markets based on decentralized energy benchmarks, carbon credit systems derived from measurable carbon sequestration, automated energy conversion contracts tied to renewable performance outputs, and much more.

The combination of blockchains and oracles presents a path forward for the energy industry, enabling it to modernize its infrastructure and meet ambitious sustainability goals that are mission-critical for corporations and industries in the 21st century.

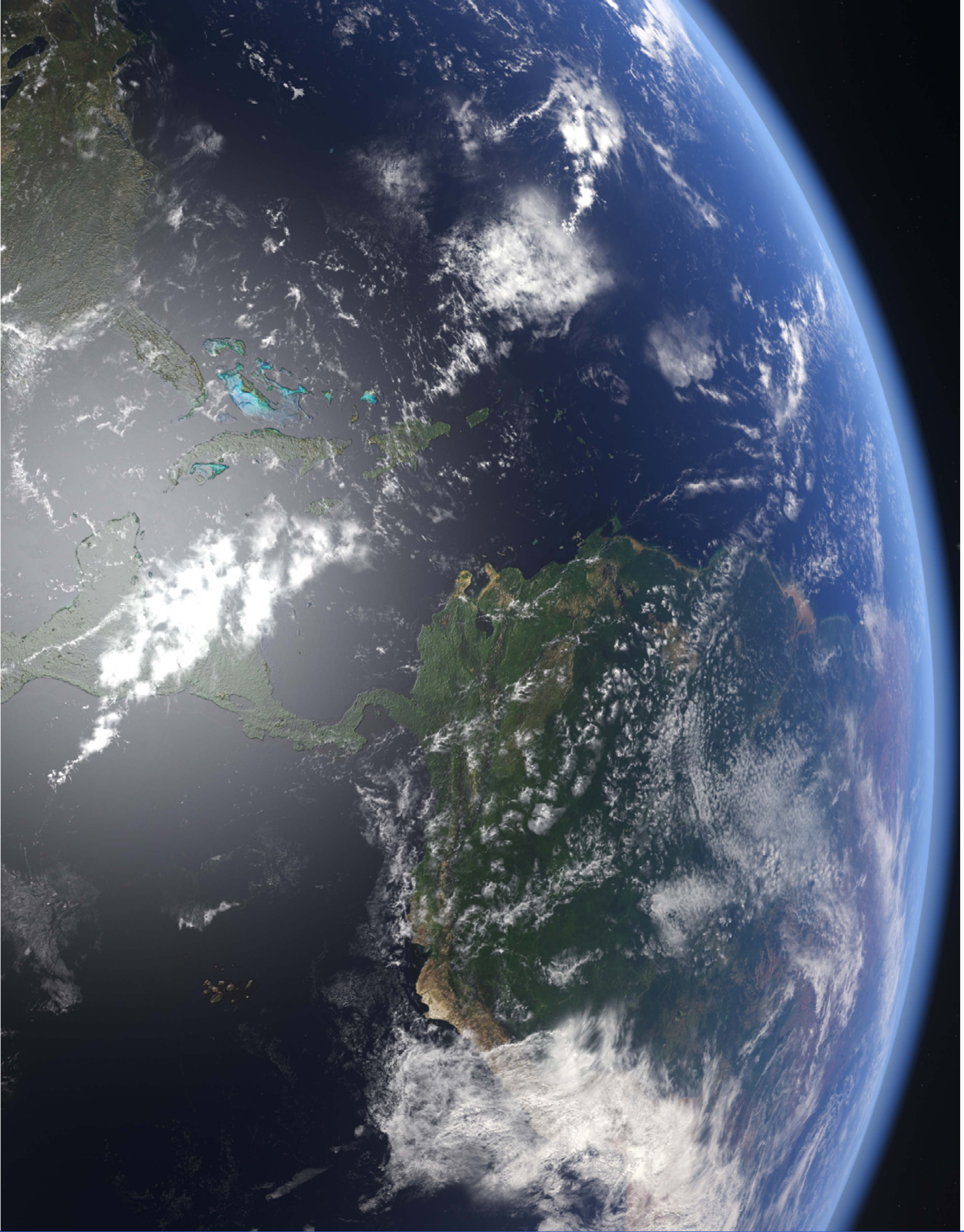


Table of Contents

Introduction

Energy is at the core of civilization. It has played a key role in the evolution of society from simple agrarian communities to an advanced, high-tech global economy. The ability to harness energy is behind most of the modern conveniences we enjoy today, such as global travel, smartphones, and the at-home appliances we take for granted. It's estimated that more than 10% of the world's annual Gross Domestic Product (GDP) is spent on energy—that's roughly $6 trillion dollars a year, making energy expenditure second only to health-care in many countries, and in some cases first[2].

Throughout history, both the production and the distribution of energy have gone through a series of massive changes. The 21st century is seeing another huge transformation: Meeting global energy demand is no longer enough—energy must be generated and supplied in a clean and sustainable manner in order to prevent the harmful effects of climate change and maintain healthy ecological systems. These new energy sector dynamics have energy companies, governments, institutions, and individuals around the world thinking more critically about how to upgrade energy grids and markets in order to meet ambitious timelines regarding the shift to clean energy.

The transition to clean energy comes with a variety of challenges, such as large investment costs, the difficulty of achieving cooperation amongst a diversified and sometimes competing set of stakeholders, and political pressure to keep energy price inflation low and infrastructure uptime high throughout the process. These challenges also intersect with geopolitical battles over energy trade dominance, disrupted labor environments and supply chain issues due to the ongoing COVID-19 pandemic, and aggressive clean energy targets set forth by governments.

Despite these ongoing challenges, new technologies are emerging that provide innovative solutions around sustainable energy production and distribution. Blockchains are one such technology, offering a new backend framework to support clean energy infrastructure. As of 2019, more than 140 research projects and startups had begun studying, testing, and deploying blockchain-based solutions with the aim of improving energy industry processes and markets[3]. Blockchain technologies are of notable interest to the energy sector because they hold the potential to improve how energy and payments are tracked and transferred across a distributed set of stakeholders and offer the ability to assign value to energy infrastructure and cash flows through tokenization.

The viability of blockchain-based green energy markets is increasing too thanks to the success of other blockchain-based markets, such as decentralized finance (DeFi) and non-fungible tokens (NFTs), which are worth over $200B+ in value and supported by established utility providers that run blockchain infrastructure such as Deutsche Telekom's T-Systems[4] and Swisscom[5]. One of the catalysts to the success of these emerging blockchain sectors has been the introduction of oracle middleware that connects existing blockchains to non-blockchain infrastructure to enable more practical hybrid "on-chain/off-chain" solutions.

The following report examines how the energy industry can leverage oracle infrastructure to support innovative clean energy solutions built on top of blockchains. Oracles play a central role in these solutions, allowing existing data providers, IoT (Internet of Things) networks, and the traditional backend systems that currently power global energy markets to seamlessly and securely interact with blockchains, thereby realizing a new development framework known as hybrid smart contracts—blockchain applications interconnected with and augmented by real-world data and legacy systems. Through oracles, trusted data streams can be inputted into blockchains to assign value to tokenized energy assets and to trigger the settlement of renewable energy contracts that depend on the verification of external events or conditions such as meteorological conditions, performance output, and emissions targets.

The report is split into four main sections:

- **First**, it looks at the ongoing changes in the energy industry that are driving the transition to clean energy. Energy industry executives will be familiar with the context outlined in this section and can skip it if they wish. For readers new to the energy industry, this section outlines the sector's current challenges and opportunities.
- **Second**, it presents a technical primer on the three core components of hybrid smart contracts: blockchains, smart contracts, and oracles. For readers new to the blockchain space, this section provides relevant base knowledge on blockchain technical concepts.
- **Third**, we examine various use cases in clean energy that are made possible through hybrid smart contracts enabled by oracles.
- **Fourth**, we present some ongoing research questions that will help accelerate the adoption of hybrid smart contracts in the energy industry, along with concluding remarks and next steps.

Ongoing Changes in the Energy Industry

To understand the potential value of blockchain-based solutions in energy, it's important to first identify the ongoing changes in the energy industry that are driving the shift to clean and renewable energy sources. Current changes can be broken down into four broad categories:

- **Demand:** climate change and increases in living standards
- **Supply:** advancements in renewable energy technology
- **Management:** decentralization of energy grids
- **Externalities:** politics, inflation, and the COVID-19 pandemic

Note: If you are already an energy expert, feel free to move to the next section. This section simply highlights the energy industry as a whole for the sake of completeness and for the benefit of those who do not have a background in the energy industry.

Demand: Climate Change and Increases in Living Standards

The single greatest driver of the transition to clean and renewable energy (RE) is the attempt to mitigate the harmful impacts of climate change by reducing CO_2 emissions—a major byproduct of energy from fossil fuels that increases global temperatures by emitting greenhouse gasses into the atmosphere. While there is still a multitude of unknowns when it comes to the potential impact of increased CO_2 across different regions of the world, there are growing international collaborative efforts to prevent catastrophic risks by meeting shared climate targets, such as the goal of limiting global warming to 1.5°C by 2050 as set out in the Paris Agreement[6] and reaching net-zero carbon emissions by 2050, a goal committed to by more than 130 countries[7].

In order to reach these goals, governments have begun introducing more aggressive measures to incentivize green investment through various subsidies, grants, rebates, and tax credits. For example, the Dutch government has enacted a Stimulation of Sustainable Energy Production (SDE+) scheme which contributes billions in public funding toward subsidies targeted at creating a 16% increase in renewable energy generation by 2023[8]. The scheme not only supports the Netherlands' own energy goals but also contributes towards the EU's target of a 40% reduction in greenhouse gas emissions (from 1990 levels) by 2030[9].

Governments are also creating new domestic and international policy frameworks aimed at increasing the minimum share of renewable energy within grids and holding stakeholders to shared clean energy commitments. Some of the various climate action frameworks proposed over the past decade include the Paris Climate Accord, the Task Force on Climate-Related Financial Disclosures (TCFD), the Taskforce on Nature-Related Financial Disclosures (TNFD), the Montreal Protocol, the Glasgow Financial Alliance for Net Zero, and the Science-Based Targets Initiative, among others.

Alongside climate science concerns, another key driver of clean energy demand is the general increase in the standard of living around the world.

Once basic needs are met, populations shift their focus towards achieving a higher quality of life and protecting the planet. Clean and sustainable energy sources are seen as a key driver in improving society, leading to reduced air pollution, better personal health, and more harmonious natural ecological systems.

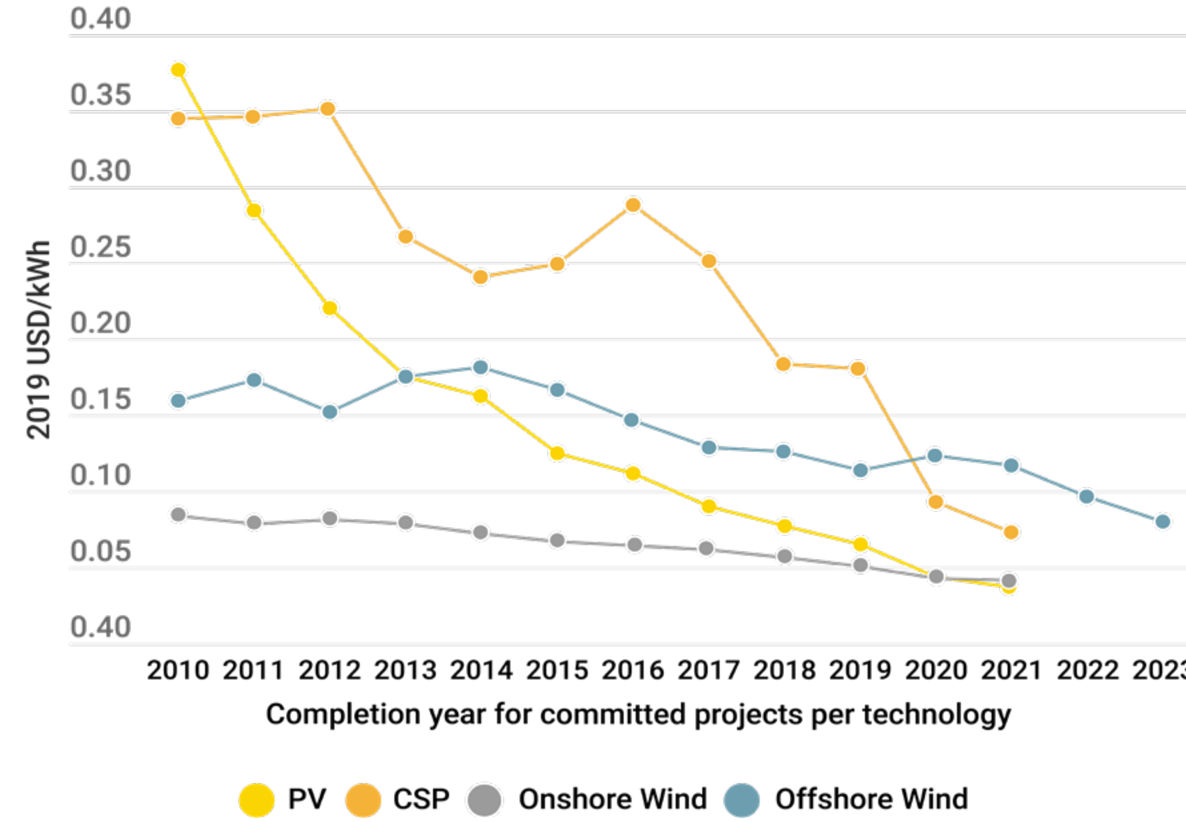
The rise in consumer demand for clean energy don't just influence personal spending habits, but also create social pressure on governments, investment funds, enterprises, and other parties to divest from fossil fuel producers and support green and sustainable investments. One byproduct of this is the rapid growth of the green and sustainability bond market, which is expected to have issued over $1 trillion USD by 2023[10]. There has also been an increase in companies developing Environmental, Social, and Governance (ESG) standards to showcase their commitment to causes like clean and sustainable energy practices to investors.

Supply: Advancements in Renewable Energy Technology

Complimenting the increased demand for clean energy is an increase in its supply thanks to technological advancements and the growth of strategic deployment processes that make the manufacture of clean energy infrastructure cheaper and its operation more efficient. Solar panels, for instance, have become vastly more efficient in recent years. Just five years ago, the most efficient solar panel for homeowners could convert roughly only 17.8% of sunlight into usable energy, while many commercial solar panels today can generate between 20-23%[11].

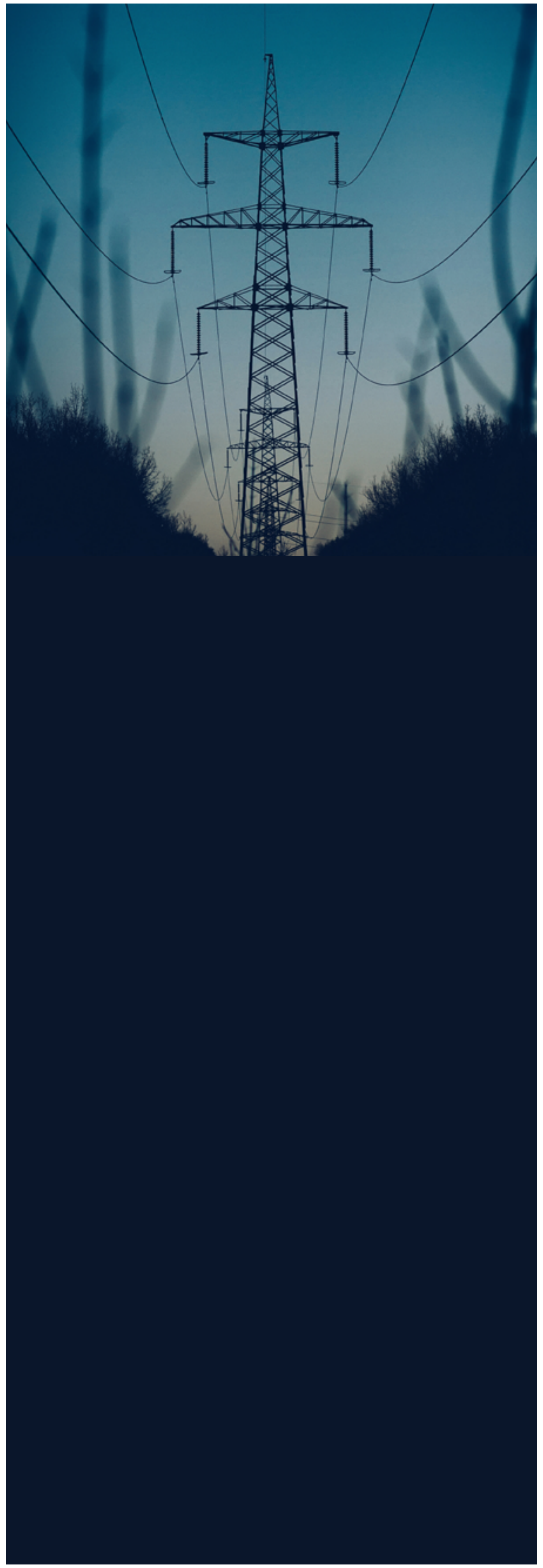
Wind turbines have also become more powerful as a result of advances in blade aerodynamics and the use of better materials, enabling them to hit higher speeds while generating less noise due to increased size and height[12]. Additionally, wind power is increasingly being deployed in off-shore locations where wind flow is unrestricted by orography. These strategic placements have led to more constant and steady wind flows, extending generator lifetime due to the alleviation of mechanical stress on generators and enabling the use of larger generators that operate continuously nearer to their rated values, as compared to on-shore units, which operate with less consistency.

Efficiency improvements have made energy generation infrastructure in the form of distributed energy resources (DERs) cheaper to build and invest in. Renewable energy prices dropped substantially between 2010-2019, with the price of solar photovoltaics (PV) down 82%, concentrated solar power (CSP) down 47%, onshore down 39%, and offshore wind down 29%. These drops in cost have made RE more competitive in financial markets against traditional fossil fuel energy sources like coal and oil. While energy prices vary greatly from country to country, fossil fuel-driven power generation usually costs between \$0.05/kWh and \$0.18/kWh (USD per kilowatt-hour). As for RE, the International Renewable Energy Agency (IREA) puts hydroelectric power costs at an of average \$0.05 per kilowatt-hour (kWh), and new power plants based on onshore wind, solar photovoltaic (PV), biomass, or geothermal energy now usually fall below \$0.10/kWh[13].



According to IRENA, since 2010, the costs associated with RE generation across solar photovoltaic (PV), concentrated solar power (CSP), onshore wind, and offshore wind have continued to drop thanks to technological advancements and strategic deployment, making RE increasingly competitive with fossil fuel energy generation.

The combination of a drop in costs and rising demand has resulted in more renewable power being added to the grid annually over the past seven years than fossil fuels and nuclear combined. In fact, it's estimated that 260 gigawatts (GW) of new renewable-based generation capacity was added globally in 2020—more than four times the new capacity added from other sources[14].



Management: Decentralization of Energy Grids

Increased supply and demand for RE presents new challenges for how to keep an increasingly distributed grid in balance while steadily increasing the share of intermittent renewable generation. This creates a dynamic where energy grids must continually support a must-serve market—consumers expect to receive energy whenever they flick a switch or plug in a device, without fail—yet continually incorporate more RE sources, which are generally less predictable in terms of output, performance, and cost.

Before looking at the various management dynamics of decentralized energy grids, let's identify some of the main stakeholders in the energy industry:

- **Independent power producers (IPPs)** generate energy and supply it to wholesale energy markets. They are often large fossil fuel power plants or industrial RE projects such as hydroelectric dams, solar fields, and wind farms.
- **Distributed energy resources (DERs)** are small-scale energy producers generally consisting of individuals, small businesses, or microgrids that consume and/or supply local energy using personal installations such as solar panels, home batteries, and electric vehicles.

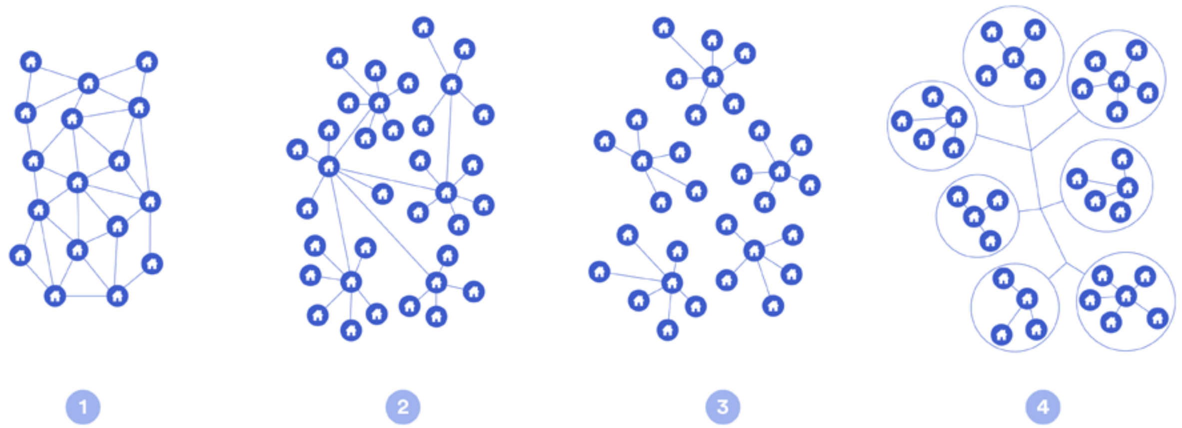
- **Prosumers** are individuals connected to the grid (mostly to the low voltage distribution grid) who have the ability to either consume electricity or to produce energy (in most cases RE).
- **Retailers** buy energy in bulk from wholesale markets and resell it to regional and local consumers. IPPs may sometimes act as retailers.
- **Consumers** purchase energy to use in their homes and for their businesses and daily lives. Large consumers are allowed to participate in wholesale markets, while small consumers can buy only through retailers.
- **Transmission system operators (TSOs)** manage transmission assets (e.g. power lines) and maintain grid balance.
- **Distribution system operators (DSOs)** manage the distribution of energy from main transmission lines to consumers.
- **Market operators** build and manage the marketplaces where energy is bought and sold, including spot, intraday, and various derivatives markets.
- **Governments** are responsible for establishing market design, monitoring for misbehavior, developing grid codes, and ensuring energy needs and goals for their jurisdiction are met.

One of the main disruptions to the energy industry is the increased usage of RE. According to the International Energy Agency (IEA), between 2019 and 2020 RE increased from 27% of global electricity generation to 29%[15]. That number is expected to rise to 45% by 2040 based on figures from the Center for Climate and Energy Solutions (C2ES)[16].

The challenge is how to incorporate the growing number of RE producers into the energy grid in order to meet climate change energy targets while continually keeping the grid in balance and energy costs low. The main problem is the unpredictable and non-dispatchable nature of RE output, meaning energy from renewable sources cannot always be generated or tapped into on-demand, nor is RE output always steady given the presence of external variables (e.g. the weather). As a result, grid operators render many residential DERs and prosumers unable to supply energy to the grid.

One of the primary reasons for this is that DSOs, whom DERs must register with before being connected to a distribution line, have historically been very conservative in accepting DERs that may compromise power equipment safety limits under worst-case conditions, which are assessed using power flow simulations. This phenomenon, often referred to as grid curtailment, is one of the main barriers to RE deployment because, in many cases, the grid has to be reinforced in order to cope with instances where RE generation is much larger than consumption.

In order to incorporate DERs and prosumers, the energy industry will need to shift its focus to a more consumer-centric approach. Such a transition will require major investments in energy infrastructure upgrades, such as the installation of more smart meters, the development of advanced load balancing services, the introduction of shared grid management platforms, and the creation of more accessible and transparent marketplaces for tracking and exchanging both energy and money. With a more interconnected smart grid, prosumers, microgrids, aggregators, and peer-to-peer energy marketplaces can be more easily integrated into the wider grid by virtue of greater predictability and real-time monitoring.



As outlined by Sussex Research Online in a paper titled Electricity market design for the prosumer era[17], there are four types of prosumer markets:

1. **Peer-to-Peer (P2P):** prosumers buy and sell energy directly from and to one another.
2. **Prosumer-to-Microgrid:** prosumers buy/sell energy through a microgrid that is connected to a larger energy grid.
3. **Prosumer-to-Island Microgrid:** prosumers buy/sell energy within a segregated microgrid.
4. **Organized Prosumer Groups:** prosumers pool resources to form virtual power plants.

Another driver of the decentralization of energy grids is Industry 4.0: a step-change increase in interconnectivity and smart automation within industrial applications. Some of the foundational elements of Industry 4.0[18] include the use of smart devices that digitally track various industrial and residential processes, machine-to-machine communication that automates data transfer and payments between devices, and advanced Machine Learning/Artificial Intelligence (ML/AI) algorithms that continually improve the efficiency and accuracy of workflows.

Industry 4.0 will have a considerable effect on grid balance, particularly given the large number of devices being brought online through smart technology. For example, grids will have to account for the proliferation of electric vehicles and e-mobility infrastructure for charging them, the addition of smart at-home appliances and large-scale battery storage, and upgrades to legacy infrastructure through the integration of various sensors and actuators.

These interconnected devices necessitate digital energy management systems that better map historical consumer profiles on energy consumption, track DER outputs within specific geographies, and understand the most efficient ways to route energy while still maximizing clean energy sources. Fortunately, smart devices have increased observability, and in many cases controllability, which can improve the predictability of demand and downscale the participation in grid management mechanisms to smaller-size DER units.

Externalities: Politics, Inflation, and the COVID-19 Pandemic

The transition to a more decentralized and clean energy-powered grid will have to overcome several separate yet interconnected externalities currently affecting energy markets. One externality is geopolitics, particularly around how to transition to clean energy when many large countries have economies dependent on the sale of fossil fuels. Competition for energy trade dominance and disagreements around energy targets and goals will undoubtedly drive political battles that require diplomatic collaboration.

Inflation is another central externality affecting the clean energy transition due to its effects on energy prices. There are a variety of policies that impact energy price inflation, such as central bank monetary policies, geopolitical disputes, consumer wages, and shifts in CO_2 prices as a result of climate change regulation aimed at reducing emissions and promoting clean energy.

Finally, COVID-19 and possible future pandemics have introduced new challenges in how to gauge energy profiles and production in stop/start work environments. Unexpected shifts in energy supply and demand due to changes in global trade or at-home consumption patterns will have to be taken into account by grid operators and governments.

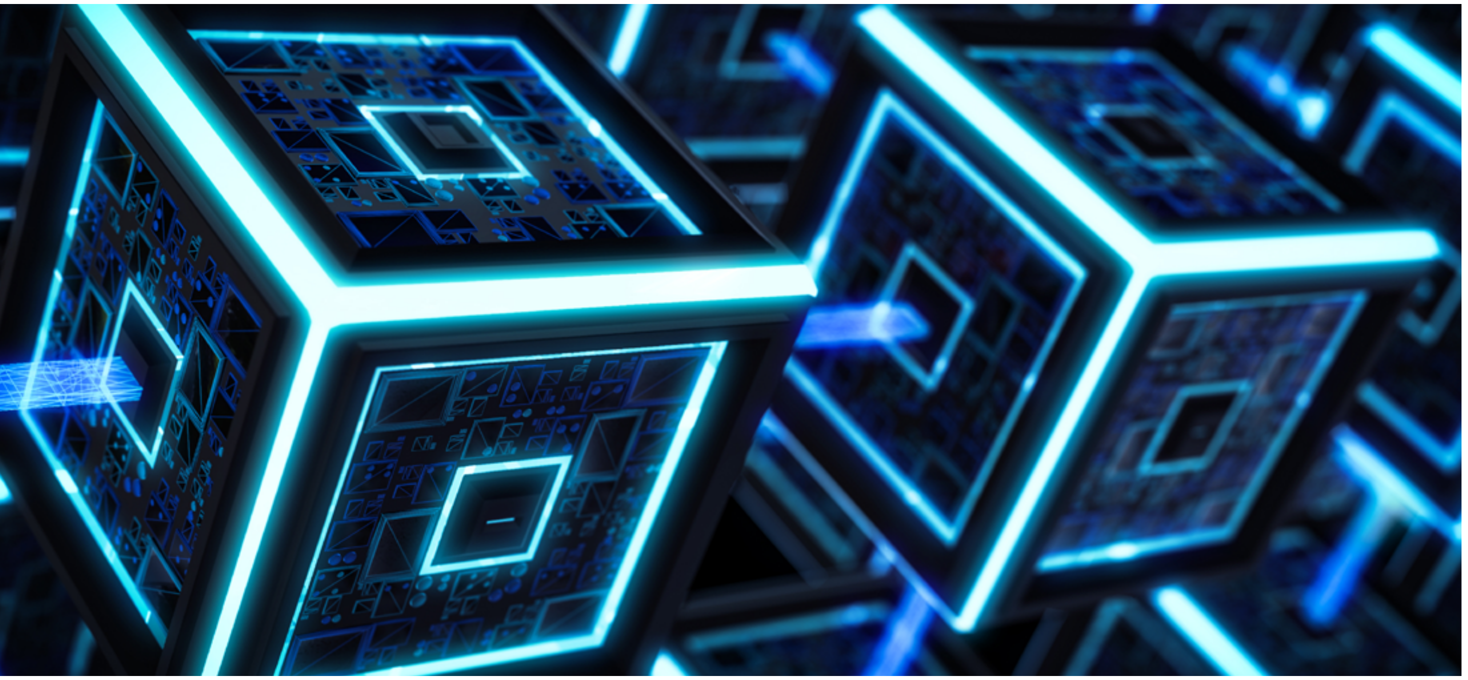
In order to respond to these externalities, it's critical to identify strategies that can dynamically tap into the most available energy reserves as needed, such as coal and gas, yet stick to the long-term goal of a sustainable and clean energy future.

Hybrid Smart Contracts: A Framework for Blockchain-Based Clean Energy Solutions

Now that we have an understanding of the ongoing changes in the energy industry, let's examine the emerging field of blockchain technology. The following section will provide an overview of hybrid smart contracts as a new backend framework for building clean energy solutions. Hybrid smart contracts consist of three core layers:

- **Blockchains:** the database and settlement layer
- **Smart contracts:** the application layer
- **Oracles: the data,** connectivity, and specialized computation layer

Note: If you are already an expert on blockchains, smart contracts, and oracles, feel free to move on to the use case section. However, this section covers the hybrid smart contract framework in depth, so it may be useful even for industry experts.

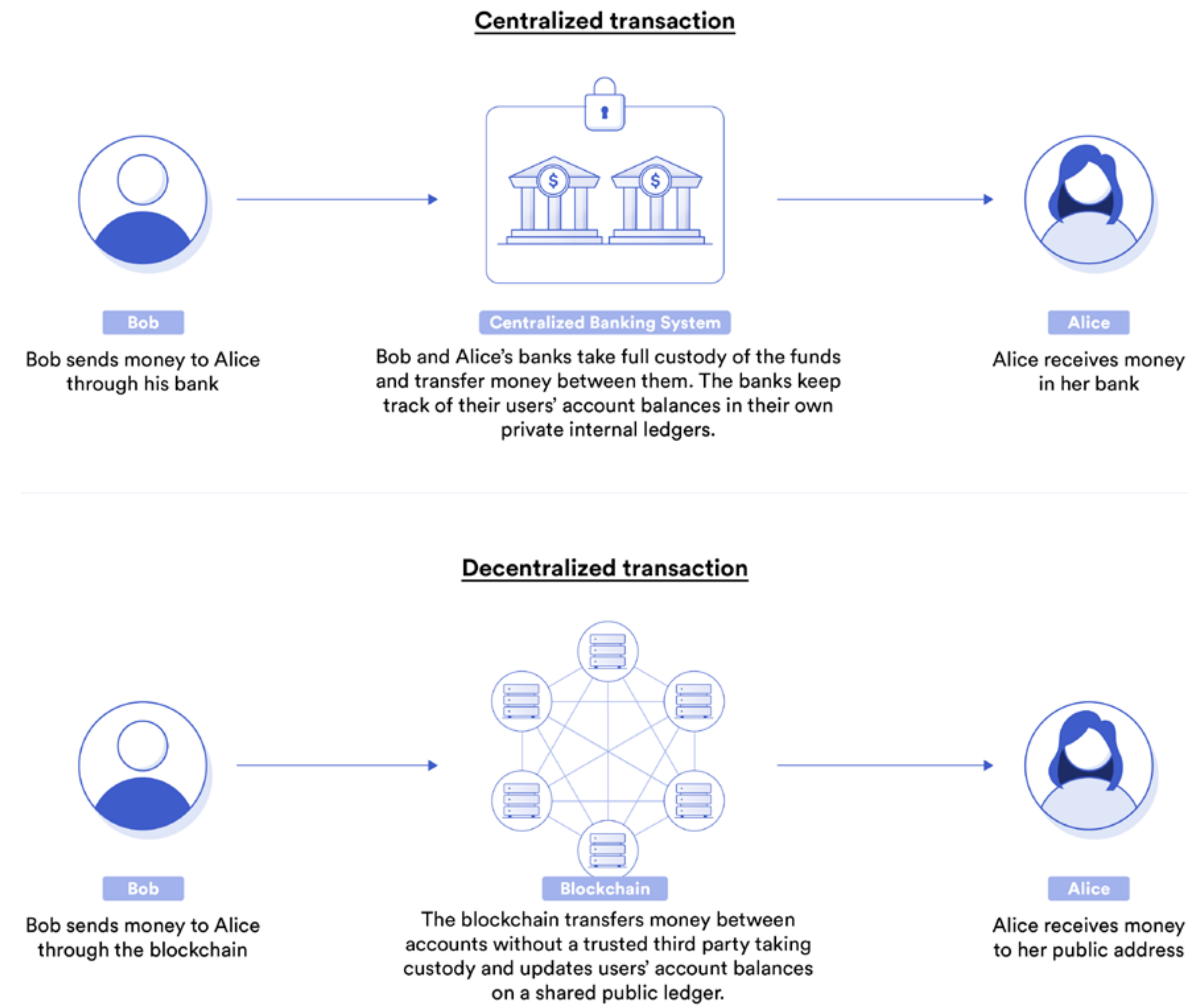


Blockchains: Database and Settlement Layer

A blockchain is a distributed ledger that tracks the ownership of all the data and/or assets held and transferred between users of its network. Blockchain ledgers consist of addresses derived from public keys, which store data/assets that can only be accessed by users with the private key unique to those addresses.

Blockchains use a decentralized network of computers (nodes) to continually extend the ledger and validate that every newly submitted transaction abides by the predefined set of rules specified in its core software before being included in a ledger update. Blockchain nodes (i.e. miners/validators) bundle pending transactions together into data structures called blocks and propose them to the network. A separate set of blockchain nodes (often called full nodes) then validates newly proposed blocks through a decentralized consensus mechanism.

The consensus mechanism is designed to get all nodes to agree that a new block of transactions is valid, such as by verifying that private key signatures match corresponding addresses, addresses have sufficient on-chain balances to cover their transactions and associated fees, and the work of other miners/validators is valid. Each newly approved block is then cryptographically linked to the previous block, making tampering extremely difficult as it would break the linear nature of the ledger.



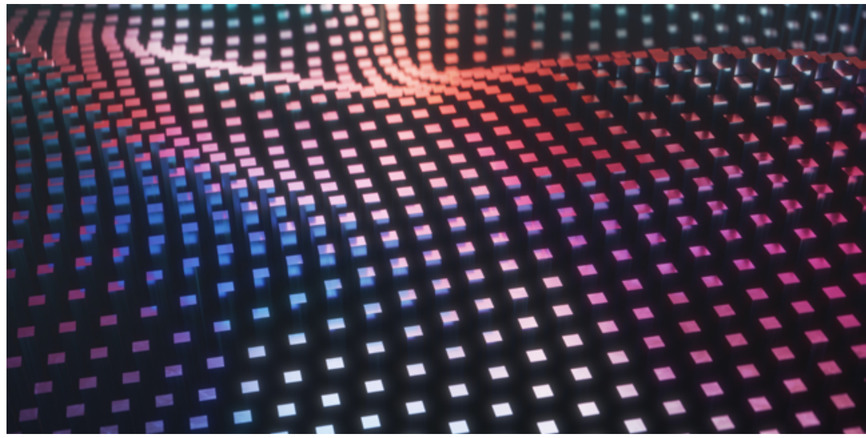
In a traditional bank transaction, the bank acts as a trusted intermediary between users in a transaction. In a blockchain payment, there is no trusted intermediary as the blockchain acts as a trust-minimized protocol facilitating the transaction.

Blockchains hold many enticing properties for users. First, blockchains eliminate the role of a central administrator and replace it with a decentralized network of participants that are financially incentivized to honestly append new blocks to the ledger and uphold the protocol rules. Decentralization and automated financial rewards/penalties (e.g. block rewards, transaction fees, and slashing) are key properties that give blockchain computation high tamper-resistance and correctness, and blockchain databases high integrity and immutability. Decentralization also leads to consistent network availability and uptime, along with permissionless accessibility for both users and developers. Furthermore, blockchains are typically very transparent, leveraging open-source software and enabling users to audit all historical transactions dating back to the genesis block.

However, not all blockchains are the same, so not all of the properties described above are equally present on all blockchains. Blockchain properties differ due to a phenomenon described by Ethereum co-founder Vitalik Buterin as the scalability trilemma (also called the blockchain trilemma[19]), which states that blockchain networks can only optimize for two out of three desired properties: decentralization, security, and scalability. Decentralization is judged by how many independent nodes have the hardware requirements to contribute to the network and store a copy of the entire ledger. Security is based on how robust against malicious attacks the blockchain is regarding the integrity of its consensus mechanism and ledger data. And scalability refers to the network's computational performance and transactions per second. There are also differences in how blockchains deal with the privacy of network transactions.

Because of these tradeoffs, blockchains vary in many ways, such as in how consensus is formed, who is able to participate in consensus, how many nodes the consensus mechanism can support, who can make transactions on the network, and how much visibility the public has around transaction details. Additionally, there are differences in how blockchains are architectured, such as having a single monolithic network of nodes performing all operations or segregating responsibilities to different layers of the stack. For example, many blockchains are now being supported by layer-2 networks, sidechains, and parallel sharding. In the blockchain ecosystem, many widely adopted networks such as Ethereum are switching their consensus mechanisms to more efficient computational models and analyzing alternatives in order to substantially reduce the energy consumption impact of blockchains.

Despite their differences, blockchains are regarded as having massive transformative potential due to their ability to create a single, well-validated source of truth for a distributed set of independent stakeholders, sometimes called a "golden record." Blockchains can also help multi-party business processes limit reconciliation discrepancies and increase efficiency by serving as a shared, censorship-resistant database and/or settlement system.



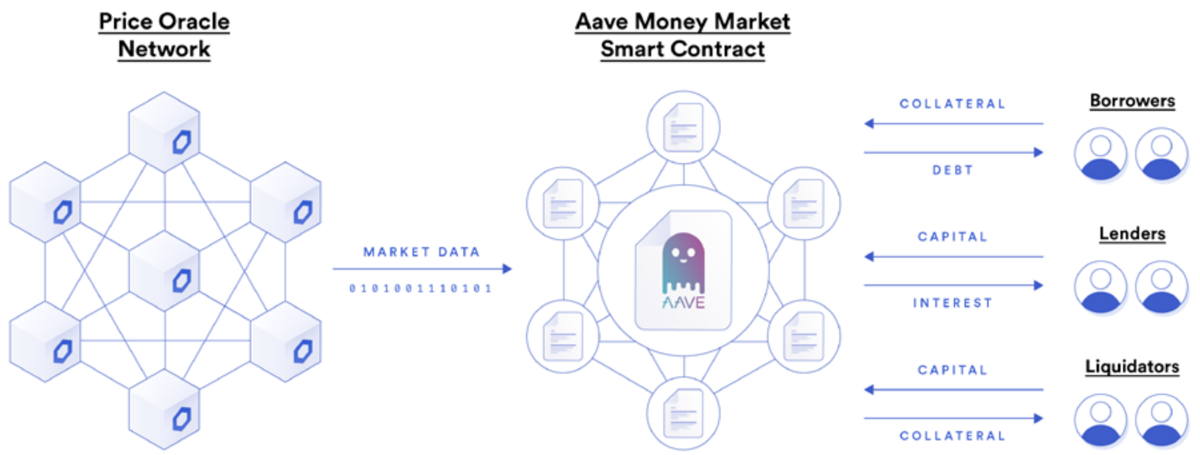
Smart Contracts: Application Layer

Though blockchains are mostly known for tracking the ownership of cryptocurrency, their ability to support smart contracts opens up a much greater value proposition around hosting tamper-proof applications and digital contracts. Smart contracts are programs on blockchains that transfer value, update applications, or document events when certain predefined conditions are met. The basic logic of smart contracts is if X event happens, then execute Y action.

Smart contracts have been instrumental in several blockchain innovations. For example, smart contracts allow a single blockchain such as Ethereum to support many different tokens beyond its native coin ETH. Each token contract serves as a mini ledger within the wider blockchain ledger, with its own set of rules and issuance schedules. Some popular token contract types include governance tokens for voting on protocol changes, utility tokens for payments or protocol insurance, and non-fungible tokens (NFTs) that represent ownership of a unique asset.

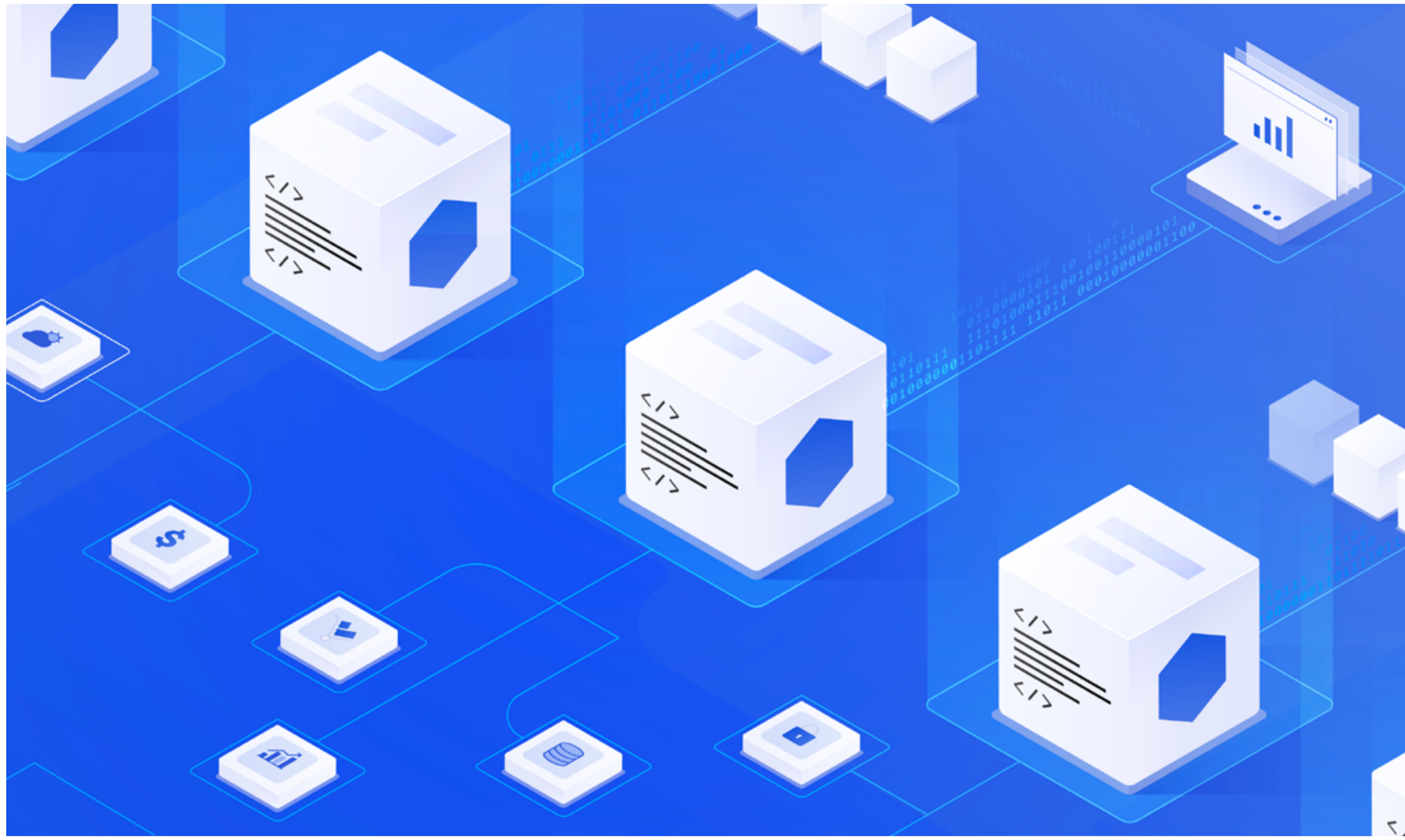
Smart contracts also enable the development of decentralized applications (dApps), which can be permissionlessly accessible to the public or deployed for a specific business process between distinct counterparties. Smart contracts define how users are able to interact in a particular dApp, setting the terms and conditions that must be met before transactions are accepted.

An example of a smart contract application in the decentralized finance (DeFi) market is Aave. Aave is a decentralized and permissionless money market that allows anyone to borrow assets by depositing collateral and lend assets to earn interest. To protect lenders' capital from insolvency, borrowers must overcollateralize their loan based on preset loan-to-collateral (LTV) ratios (e.g. 150%). If the borrower's LTV ratio falls below the predefined LTV ratio, then their deposited collateral can be liquidated and transferred to the lender.



Aave uses a hybrid smart contract framework to support permissionless decentralized money markets on blockchains that issue loans to borrowers, liquidate undercollateralized loans, and distribute interest payments to lenders without a centralized custodian.

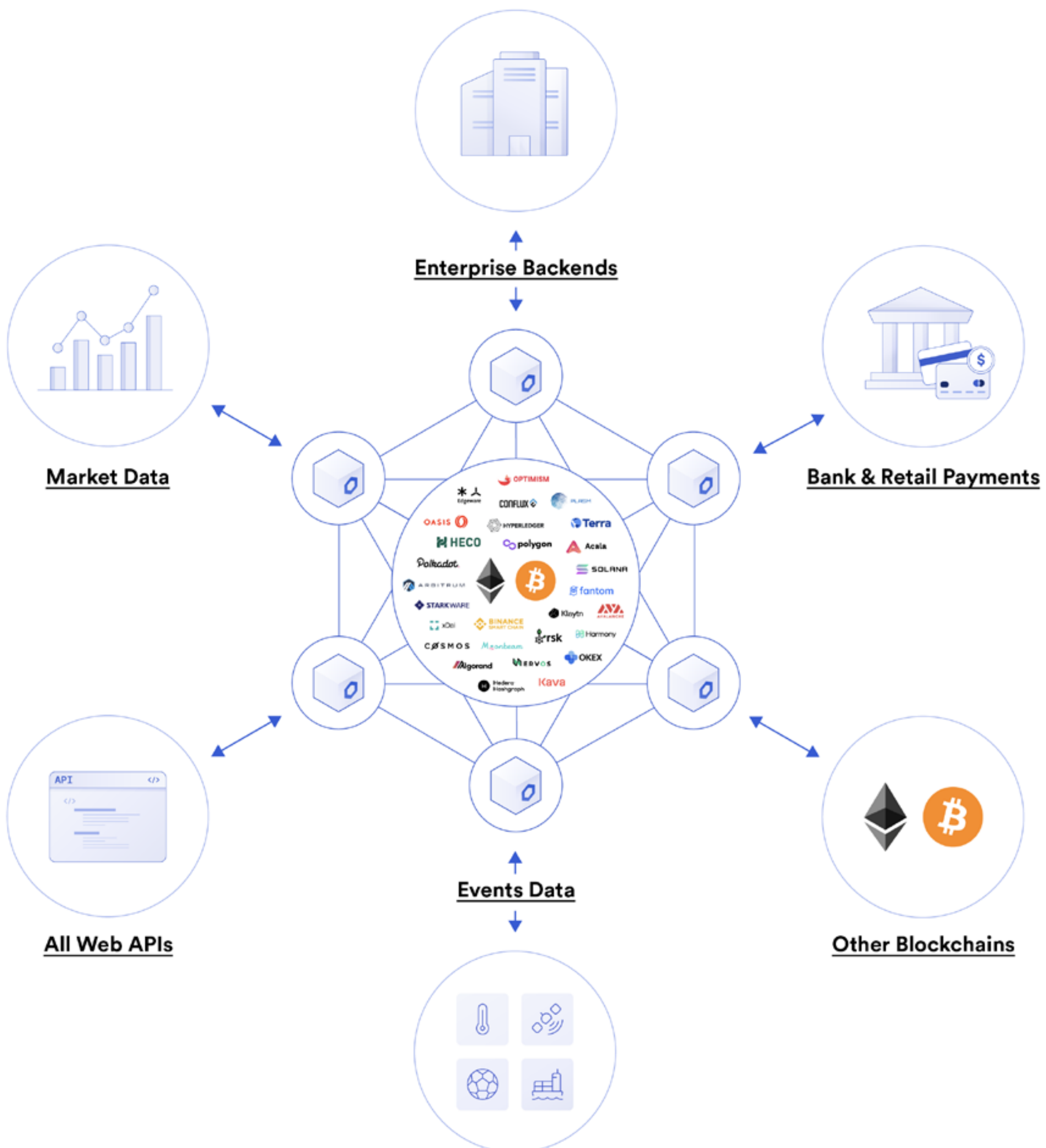
The value created by smart contracts lies in their ability to reduce counterparty risk and increase the efficiency of digital agreements. Participants in a smart contract have strong assurances that the contract terms and conditions will be honored exactly as submitted to the blockchain. No longer can a single counterparty, particularly one with more capital and power at their disposal, influence the outcome of the contract by unilaterally changing the terms of the agreement, refusing to pay what they owe, or bullying a smaller counterparty with expensive litigation. The reduction in counterparty risk and increase in reliability enabled by smart contracts have many excited about the ability of blockchains to support new automated, data-driven business processes and applications.



Oracles: Data, Connectivity, and Specialized Computation Layer

One of the fundamental limitations of blockchains is that they are isolated networks, inherently disconnected from other networks or systems. This lack of external connectivity is referred to as "the oracle problem[20]," and results in smart contracts having no built-in mechanism with which to read from and write to external Application Programming Interfaces (APIs).

Without bidirectional communication with the outside world, smart contracts can only be created around data generated internally by the blockchain and executed based on the computational capacity of the underlying blockchain. The result is smart contracts that are inherently unable to verify real-world events, interact with legacy infrastructure, or perform more specialized computations. Such limitations present a major problem for smart contract adoption given that the vast majority of contractual agreements that may be conducive to being codified as a smart contract will require inputs, outputs, and computations only accessible outside the blockchain (off-chain).



The Chainlink decentralized oracle network provides smart contracts on any blockchain with the ability to connect bidirectionally with any external system or resource.

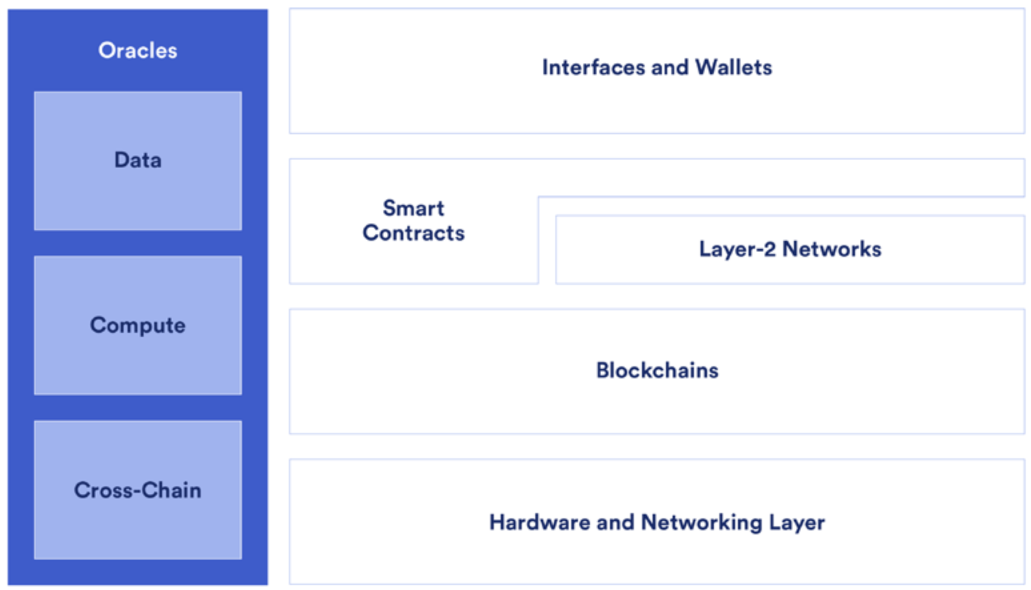
For instance, smart contracts cannot inherently ingest external inputs to trigger their execution, such as weather data for determining the payout of a parametric crop insurance contract or IoT data to confirm whether or not goods arrived prior to paying the manufacturer. The range of external data inputs a smart contract may need is vast, spanning asset prices, meteorological data, IoT sensor readings, sports match results, enterprise backend information, and much more.

The oracle problem also means that smart contracts are unable to send outputs to external systems. For example, a smart contract may want to send a payment instruction to a traditional payment rail in order to settle an agreement in local fiat currency as opposed to settling it on-chain in a cryptocurrency. A smart contract may also want to influence an off-chain cyber-physical system or IoT network once certain conditions are met, such as opening a rental home when the guest's ID is verified or turning off a prosumer's energy supply to the grid when market demand is low.

Finally, more and more smart contracts need to move data, assets, and commands between disparate blockchains. Blockchain interoperability is key to enabling a wider range of use cases, such as cross-chain applications that fetch data from one blockchain, execute contract logic on another, and make settlement payments on a third. It's also important for large enterprises and institutions that deal with a multitude of separate counterparties around the world that each have their own blockchain preferences.

In order to overcome the fundamental limitations of blockchains, smart contracts need to make use of an additional piece of secure middleware known as an oracle. Oracles are entities that provide smart contracts with any data and computation that they cannot inherently access on their native blockchain. Oracle services often involve service level agreements (SLAs) between the oracle and requesting user, which outline the service terms, rewards, and penalties regarding the oracle's performance.

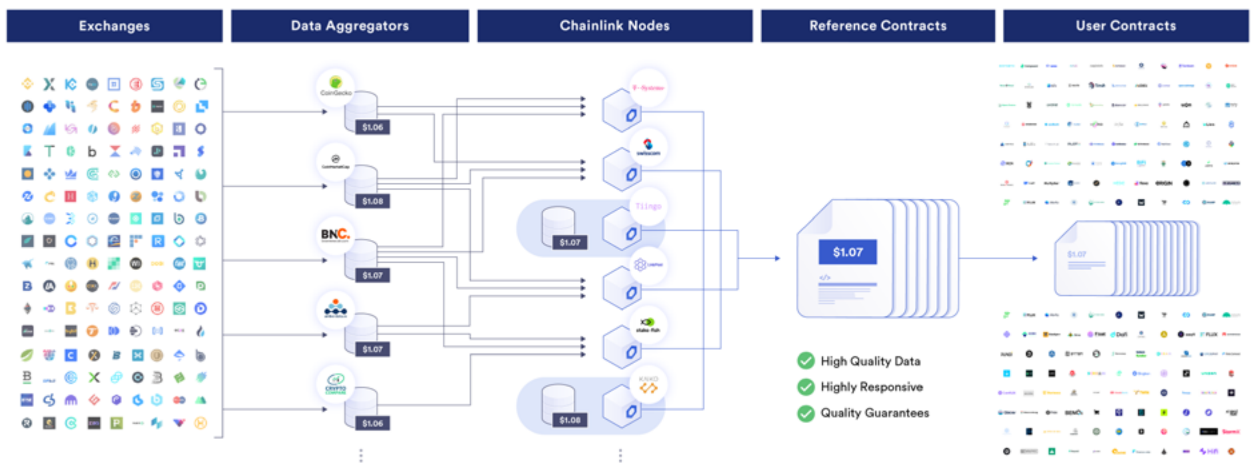
While oracles are widely recognized today for supplying data from external APIs to blockchains, they function more broadly as a flexible off-chain substrate that can be tasked with providing any service to a smart contract—in a manner that fits the users' own trust assumptions, budget, and performance requirements. This includes connecting smart contracts to external data inputs, delivering outputs to external systems on behalf of smart contracts, serving as a specialized execution layer for trust-minimized computation, and facilitating cross-chain interoperability.



Oracles support numerous layers of the Web3 stack[21], providing trust-minimized data, computation, and cross-chain services.

Since oracle services are performed off-chain and directly affect the outcome of smart contracts, it's important that oracles employ a variety of trust-minimization techniques to ensure the end-to-end security and reliability of the on-chain application. Trust-minimization refers to the security and reliability of a process becoming more deterministic as opposed to reliant on unknown, uncontrollable, or unpredictable variables such as human intervention and centralized systems.

One of the main trust-minimization techniques of oracles is decentralization, both at the oracle node and data source levels. Chainlink, the industry-standard oracle network, pioneered Decentralized Oracle Networks (DONs), an architectural model that helps prevent any single node from disrupting the final result and/or any single data source from being the single source of truth. Chainlink oracles also cryptographically sign data on-chain to verify its origin, forming the basis for monitoring and reputation systems that track real-time responses and verify the historical performance quality of oracle nodes.



Chainlink Price Feeds, which currently help secure billions of dollars in value across the Decentralized Finance (DeFi) ecosystem, are decentralized oracle networks that provide real-time asset prices to smart contract applications using a three-tier aggregation method.

1. **Data Aggregation:** Professional data aggregators generate volume-weighted average prices (VWAPs) for specific assets from raw data across hundreds of centralized and decentralized exchanges.
2. **Oracle Node Aggregation:** Chainlink nodes fetch VWAPs from multiple independent data aggregators and take a median value.
3. **Oracle Network Aggregation:** The median values of numerous independent Chainlink nodes are further aggregated into a median to create a single trusted value that is stored on-chain in reference contracts for DeFi applications to query on-demand.

Oracles can also deploy more advanced trust-minimization techniques, such as using zero-knowledge proofs (ZKPs) to bring sensitive data on-chain without publicly revealing it[22], running computation in trusted execution environments (TEEs) to ensure high integrity and confidentiality[23], staking cryptocurrency as collateral insurance to back oracle SLAs[24], and implementing fraud detection networks that monitor oracle services and trigger failsafes when inaccurate or malicious activity is detected.[25] Smart contracts can also route specialized computation off-chain

to oracle networks for higher trust-minimization guarantees than traditional computing for purposes such as achieving greater scalability, additional privacy, or the ability to perform more advanced functions within their applications.

Ultimately, oracle networks enable smart contract applications to transition from purely on-chain code to an interconnected fusion of on-chain and off-chain code with end-to-end security. These hybrid smart contracts not only allow blockchain-based applications to interact seamlessly and securely with the existing non-blockchain world, but they also empower a range of customizations needed to create real-world value. Their ability to supply key off-chain services makes oracles a critical component in unlocking a number of clean energy solutions powered by hybrid smart contracts.

Use Cases in Clean Energy With Hybrid Smart Contracts

Having understood the energy industry challenges and opportunities and the architecture of blockchains, let's dig deeper into some examples of potential use cases that open up a whole new world of opportunities in the energy industry. Hybrid smart contracts allow for a wide variety of use cases that can support the transition to clean energy and help society manage its climate change objectives. The hybrid framework uses blockchains to reliably track and settle multi-party processes, smart contracts to define the rules of engagement for all involved parties, and oracles to seamlessly and securely integrate real world data and traditional non-blockchain infrastructure into these more powerful digital contracts.

Outlined below are eight potential use cases in clean energy that are enabled by hybrid smart contract infrastructure.

1. **Tokenized carbon credits**
2. **DeFi energy derivatives markets**
3. **On-chain climate and green bond ratings**
4. **Tokenized cash flows from clean energy projects**
5. **Energy conversion contracts**
6. **Parametric insurance for renewable energy infrastructure**
7. **Consumer rewards for sustainable consumption**
8. **Grid management**

Tokenized Carbon Credits

While many countries are making strides in their transition to renewable energy, fossil fuels are unlikely to completely disappear anytime soon due to their deep integration in existing processes. To disincentivize carbon emissions, some jurisdictions have introduced cap and trade carbon credit systems, with companies required to stay within allowances or buy carbon credits to offset their emissions, either in the form of offsets or credits from other companies.

Carbon credits allow a company to emit one ton of CO2 because an offset project captures one ton of CO2 from the environment, such as through renewable energy investments, reforestation, carbon capture technologies, and more. Companies are also able to purchase carbon credits from other companies that emit less than their allowance. Carbon credits help companies meet their Environmental, Social, and Governance (ESG) goals and governments meet their climate change objectives. However, one of the challenges is verifying the integrity of offset projects.

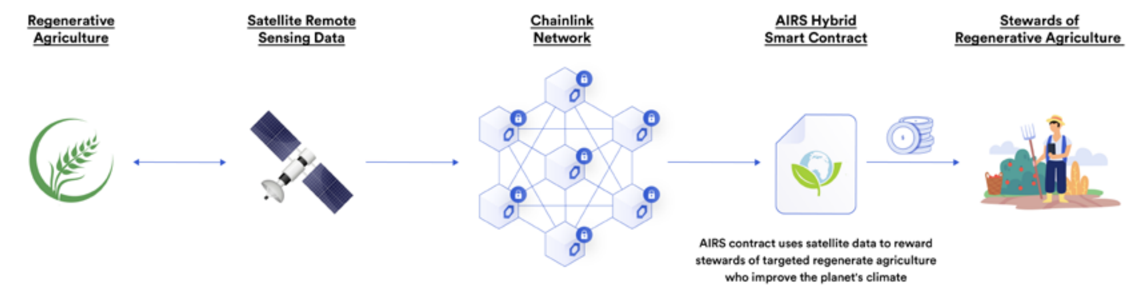
Blockchains can offer carbon credit systems a transparent and globally accessible ledger for storing carbon credits as digital tokens. These tokenized carbon credits can then be more easily tracked and traded around the world or within certain regions, along with having a standard format and historical record of ownership. Oracles can enhance the integrity of tokenized carbon credits by helping both issue and audit carbon credits.

For example, oracles can use IoT, satellite, and remote sensing data to measure the carbon sequestration in a particular geographic region to verify a project's stated CO2 offset before issuing a carbon credit. Projects like Hyphen, a hybrid smart contract system for accurate emissions reporting, is using Chainlink oracles to deliver verified greenhouse gas (GHG) data on-chain and prove corporate climate commitments in accordance with the Paris Climate Accord and Montreal Protocol, an international treaty around managing ozone depletion.[26] Oracles can also supply data from professional auditors, third-party rating agencies, and regulators regarding the estimated value of existing carbon credits, which can then be used to price them within traditional and DeFi markets.

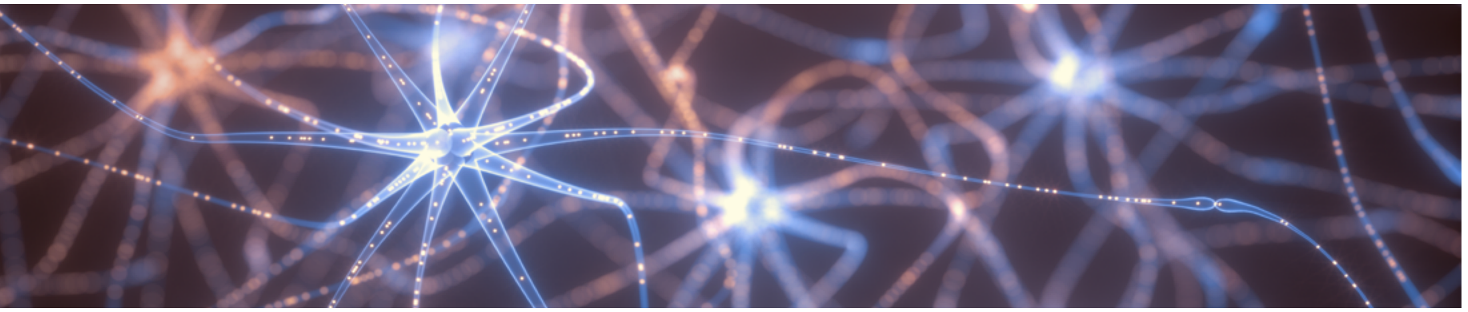
CASE STUDY

Green World Campaign: Regenerative Agriculture Powered By Hybrid Smart Contracts

Green World Campaign is a company that aims to incentivize regenerative agriculture through its AIRS project—a hybrid smart contract application that uses satellite and ground-truthing data to automatically dispense financial rewards to people who successfully regenerate designated areas of land by improving soil health, contributing to greater carbon sequestration, increasing vegetative/tree cover, enhancing hydrology, and other rehabilitation techniques. [27]



AIRs is integrating a Chainlink-powered decentralized oracle network that runs in a trusted execution environment to fetch data, analyze it for high-trust qualitative metrics, and then trigger payouts to stewards who successfully regenerate agriculture in their specific geographic region. AIRS will issue these regenerative carbon assets as tokenized Green World Credits on the blockchain, which are then sold to institutions and public crowdfunding campaigns aimed at natural restoration. The stewards receive rewards in cryptocurrency—readily convertible into their local currency—or digital financial instruments tailored to meet the needs of local communities.



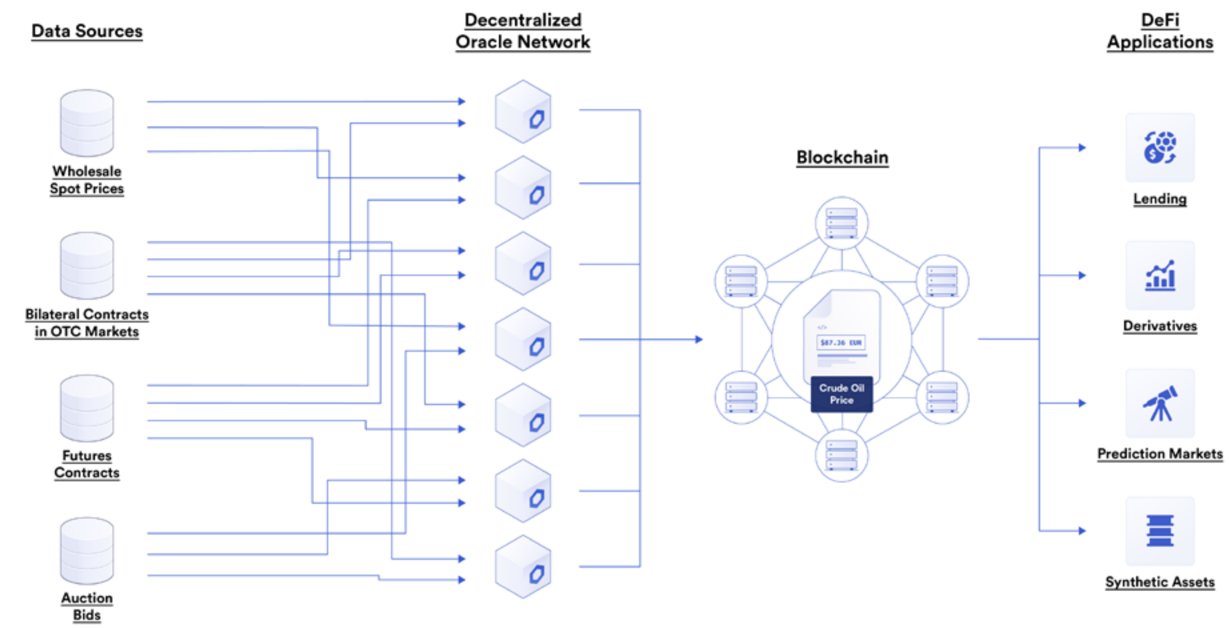
DeFi Energy Derivatives Markets

Decentralized Finance (DeFi) is currently the largest market for blockchain-based smart contracts. DeFi leverages smart contracts to build tamper-proof, transparent, non-custodial, and permissionless financial applications and products such as lending markets, decentralized exchanges, algorithmic stablecoins, synthetic assets, derivatives contracts, and more. Going by the total value of cryptocurrency locked up as collateral in DeFi applications, DeFi is a $250+ billion dollar market at the time of writing, placing it in the top 50 for national GDP.[28]

Oracles are a foundational component of many DeFi applications, providing smart contracts with external financial market data such as real-time asset prices. For example, smart contracts use asset prices to support derivatives contracts and collateralized loans. In such cases, the oracle mechanism is key to setting the starting price and exercise/expiry price at settlement in the derivatives contract, and determining the collateralization of the loan during issuance and potential liquidation.

By leveraging high-quality data feeds on blockchains through oracles, the energy industry can build its own set of DeFi applications. A decentralized oracle network (DON) can provide on-chain decentralized indexes for energy commodities such as crude oil, heating oil, natural gas, and gasoline. These oracle-based indexes can also target other key industry metrics, such as the current prices for solar power, wind energy, green certificates, and various ancillary services.

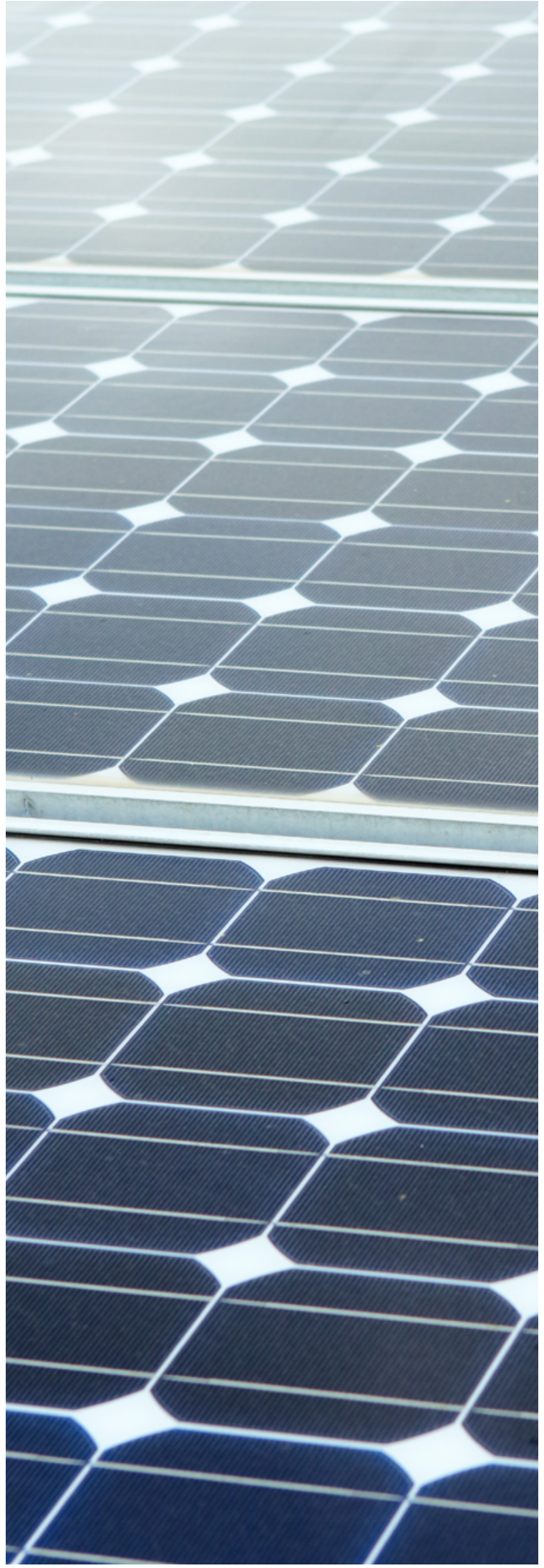
Decentralized energy indexes can be generated by having the DON collect spot prices in wholesale markets, over-the-counter (OTC) transactions from submitted bilateral contracts, futures contracts, and even submitted bids in auctions. Oracles can aggregate the data from a multitude of premium data providers already widely trusted by the industry or have the data providers themselves run oracle nodes to supply and cryptographically sign their own data onto the blockchain. The index prices can be customized to support different weights and sets of stakeholders, such as at the wholesale or retail level or based on a particular geographic location or jurisdiction.



Oracles can form the backbone of new decentralized energy indexes that enable DeFi applications for the energy industry across lending, derivatives, and more.

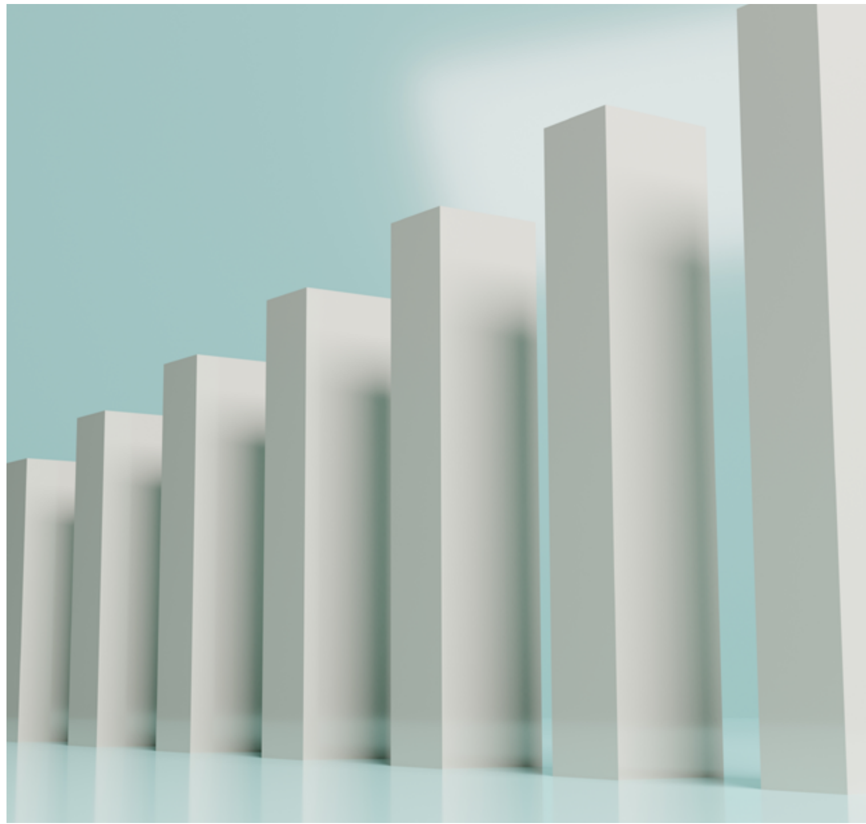
The use of oracles to create decentralized energy indexes on blockchains would enable broader creation of and access to new types of DeFi products and services for the energy industry, such as futures/options contracts, swaps, prediction markets, and synthetic assets. Market participants can leverage these DeFi instruments to hedge against fluctuating energy prices and outputs, achieving more stability and predictability during volatile periods. At the same time, the industry as a whole would benefit from decentralized energy indexes that are calculated in a more transparent and aggregated manner.

On-Chain Climate and Green Bond Ratings



Similar to how carbon credits can be tokenized, a variety of other green investment vehicles can also be tokenized on blockchains, such as climate bonds and green bonds—fixed-income instruments that raise money for climate and environmental projects. Having a more global, historically trackable financial market based on blockchains could bring more integrity and access to new types of green investments. However, the problem remains of how to assign value to green investments in a manner that investors can trust.

Oracles can form the basis of decentralized on-chain rating systems for tokenized climate and green bonds. For instance, oracles can aggregate data from auditors, independent rating agencies, and regulators regarding their estimated bond valuations in order to come up with a single, trusted value. The trusted value can then be relied on by DeFi applications to support tokenized green bonds as collateral for loans or serve as a trading benchmark. Access to such data on-chain could help broaden the utility of green investments and help reduce risk through a more reliable and transparent valuation model that cannot be easily corrupted or overly influenced by a single entity.



Tokenized Cash Flows From Clean Energy Projects

Many people around the world are passionate about the transition to a more sustainable and clean energy model. With this passion comes the desire to invest in clean energy projects. However, it's not always easy to reliably invest in such projects, especially when they're not available in your immediate jurisdiction.

One way to improve this could be asset tokenization, where participants buy blockchain tokens that represent equity and/or cash flows in RE projects such as wind farms and solar fields. Oracles can be applied to the dividend distribution processes as a means of gathering revenue data and performance output from smart meters to then calculate cash flow payouts to token holders. These metrics can then be stored on-chain as immutable records to verify the productivity of the investment and inform future initiatives. In some instances, these projects might even be managed through a Decentralized Autonomous Organization (DAO), where token holders help manage the project through on-chain voting on decisions such as determining management positions and deciding how to direct treasury funds.

Energy Conversion Contracts

The production of non-dispatchable renewable energy can be quite volatile due to its dependence on non-controllable external variables. For example, a solar panel installation will generate less energy on a cloudy day, just as a wind farm will generate less energy on a day without much wind.

As the number of intermittent RE installations grows, it's essential to have procedures and services that ensure their proper functioning, particularly to guarantee the profitability of investments and consolidate technology as a reliable and viable energy solution. Consequently, providing operation and maintenance (O&M) for these installations is becoming increasingly relevant in the sector. A professional O&M service must ensure that the RE installation maintains a high level of energy performance and is economically practical over time.

The main performance indicators that must be guaranteed in an O&M contract for an RE installation are also affected by the design and construction of the installation. Thus, these commitments must generally be acquired at the engineering and execution stage of projects, being essentially compulsory for a turnkey project supplier.

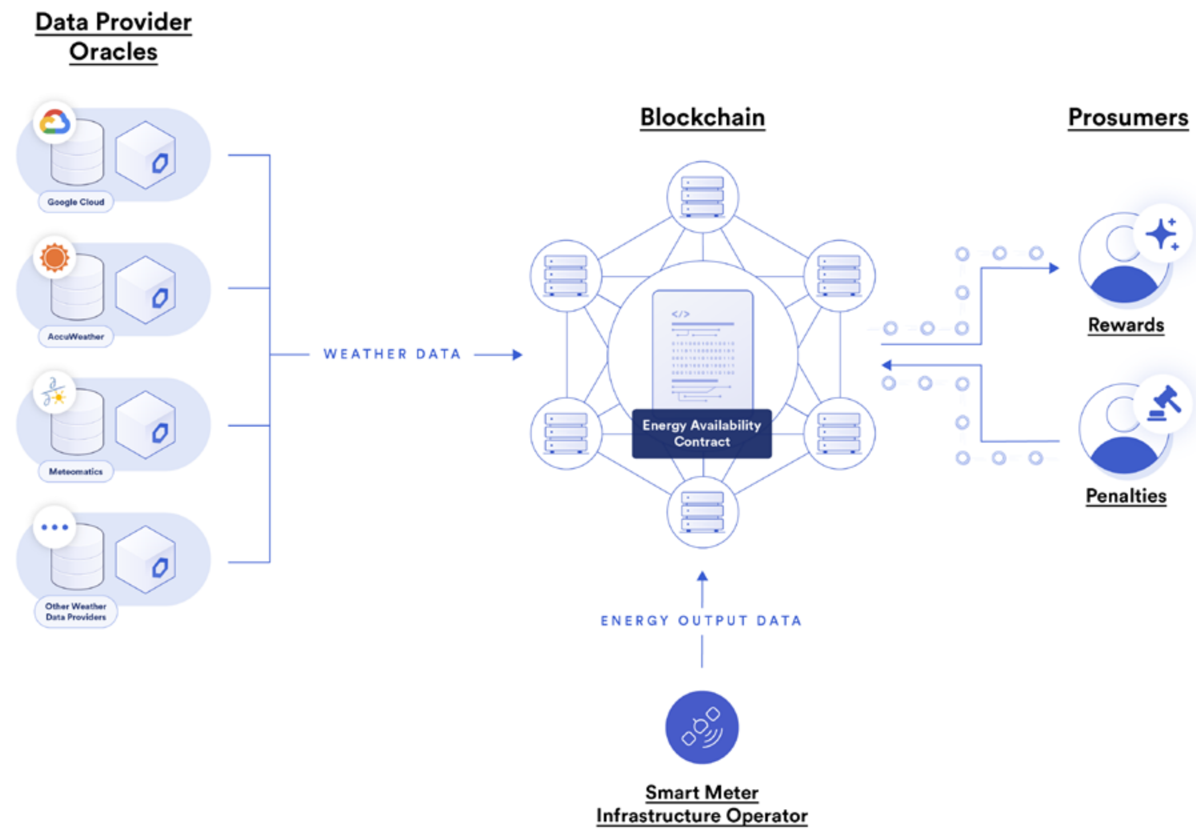
One of the ways to account for the performance of RE installations is through energy conversion contracts, which are drawn up between a manufacturer and/or installer and its client, and include reward and penalty clauses around the energy conversion ratio of the renewable energy installation. Usually, the Resource Manager provides the O&M service of the RE installation, guaranteeing a certain level of performance to the client. The Resource Manager must meet these performance indicators or face a damage settlement scheme, in which the client will be compensated for poor performance of the installation. It is necessary to collect by contract other factors outside the Resource Manager's responsibility that may affect the production of the installation, such as force majeure events or the unavailability of the distribution network, which are exempt from the liability of the Resource Manager and, therefore, excluded from the settlement of damages.

Energy conversion ratios are tied to KPIs such as performance ratios—maintaining certain performance outputs in various weather conditions, or energy availability—and maintaining the uptime of RE installations. Settling these contracts requires smart meter data and weather data to determine if the KPIs were met, as KPIs reflect the ratio between the expected production (based on real weather conditions) versus the real production of a RE installation (measured with smart meter infrastructure).

In order to facilitate the penetration of RE installations, energy conversion contracts need to become more widespread at the local level. One potential solution is using hybrid smart contracts to automatically trigger rewards and penalties based on energy conversion ratios, enabling the monitoring of the performance indicators of the RE installation through blockchain technology. This approach would guarantee compliance with the contractual conditions of energy performance agreed upon by the client and also help reduce

prospective customers' uncertainty around investing in RE solutions.

In this scenario, oracles can play a key role in enabling such hybrid smart contracts by sourcing weather data, such as wind speeds and cloud coverage at specific times within specific geographic regions, and then delivering the data on-chain to trigger payouts and penalties from energy conversion smart contracts. In fact, some of the top weather data providers in the world, including AccuWeather and Google Cloud, are already running nodes on the Chainlink oracle network to supply weather data on blockchains. By aggregating cryptographically signed weather data, contract participants have full transparency into the exact weather conditions that are used to trigger a contract's outcome.



Energy conversion contracts based on energy availability can be built as hybrid smart contracts. For example, professional weather data providers and DSOs can operate their own Chainlink oracle nodes to supply data on-chain used to trigger rewards/penalties.

In addition to providing access to real-world weather data, oracles can help bring energy output data from RE installations on-chain. The output production data can be fetched from smart meters, user portals (e.g., DSOs in Spain), national regulated smart meter infrastructure operators (e.g., DCC in the UK), or third-party IoT networks. With both weather and output data available on-chain, energy conversion hybrid smart contracts can automatically execute and settle in real-time.

Parametric Insurance for Renewable Energy Infrastructure

RE installations often involve high upfront costs and long-term financing commitments. Similar to energy conversion contracts, weather patterns play a critical role in determining whether or not projects or individuals meet their target outputs each year. While it's important to research the location of installations beforehand, the unpredictable effects of climate change over time may necessitate demand for new parametric insurance plans for RE infrastructure, both on an individual and an industrial scale.

Oracles again play a key role in bringing high-quality weather data from specific geographic locations onto blockchains to trigger parametric insurance payouts. Not only does this help RE projects hedge unknown weather risks, such as reduced wind speeds, extended periods of cloud coverage, and even extreme events such as hurricanes, but it may also incentivize individual prosumers and businesses to invest in solar installations knowing that they will receive fair and timely payouts on weather insurance plans. Insurance plans can also support RE projects with tokenized equity models as a way to help token holder investors hedge risk.

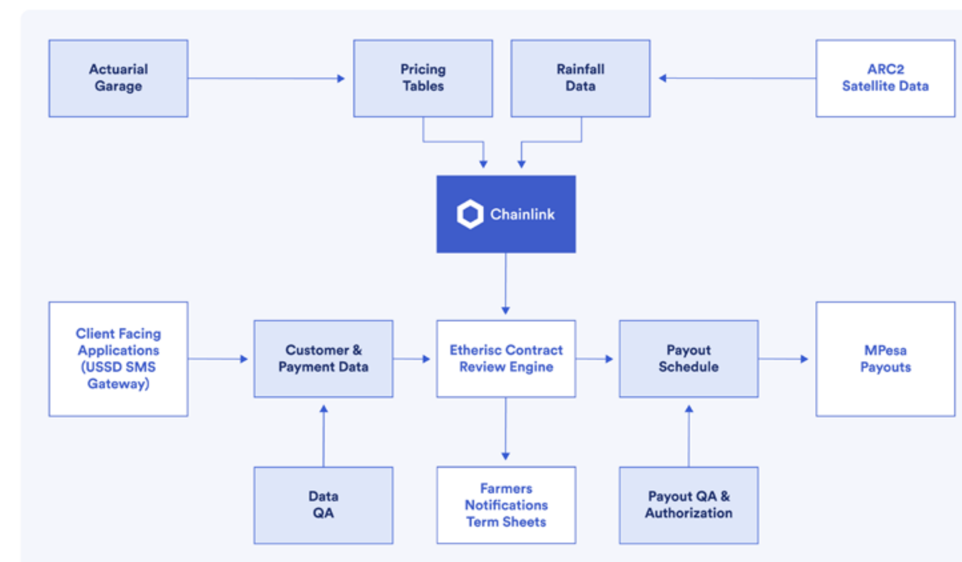
A growing number of parametric insurance platforms have emerged that leverage oracle-powered weather data feeds and blockchain-based settlement to automate insurance assessments and payouts for both agribusinesses and energy producers. Arbol is one example of an Ethereum-based climate risk solutions platform that uses smart contracts and oracles to help energy businesses hedge power demand and revenue fluctuations around unexpected temperature variations. For both insurance providers and policyholders, the parametric coverage model enabled by hybrid smart contracts brings increased transparency, automation, and auditability to the entire lifecycle of the insurance product.

CASE STUDY

ACRE Africa: Weather-Based Parametric Insurance for Smallholder Farmers in Kenya

Weather-based parametric insurance on blockchains has already been demonstrated in-production through a collaboration between ACRE Africa, Etherisc, and Chainlink. Over 22,000 Kenyan farmers were insured against weather-related risk to their crop yields during the harvest seasons in 2021, with Chainlink oracles supplying weather data that triggered payouts directly to farmers via MPESA's mobile payment gateway[29].

acre AFRICA ETHERISC



This innovative insurance model expedites claims processing and payouts, improves transparency and auditability through on-chain notarization, and ultimately reduces the cost of premiums for policyholders. With only 3% of smallholder farmers in Sub-Saharan Africa using agricultural insurance coverage to protect themselves and their families' livelihoods against climate change, this project showcases the potential for blockchain-based parametric insurance to bring economic sustainability to emerging markets during our era of increased climate risk.

Consumer Rewards for Sustainable Consumption

Cutting and/or reshaping the energy demand of individuals is also key to avoiding the harmful effects of climate change. One of the best ways to encourage consumers to reduce their emissions, or at least better optimize their appliances as a means of reducing their overall carbon footprint, is to participate in Demand Side Management (DSM) programs.

DSM involves different measures that influence the customer to modify their demand pattern (how much and when they consume) in order to both save on net energy consumption and facilitate more efficient usage. Examples of DSM programs are Energy Efficiency Programs, in which consumer assets are substituted by newer (and more efficient) assets, and Demand Response (DR) Programs, in which consumers and/or their assets react in real time to accommodate their consumption patterns. Examples of DR programs are Dynamic Pricing Programs, Direct Control Programs, Indirect Control Programs, and Flexibility Markets Programs. DR programs are usually launched by retailers that want to optimize their portfolio or by DSOs that want to avoid local congestion issues. The common ground of these programs is that both retailers and DSOs play the role of Flexibility User and request consumers to act as Flexibility Providers in exchange for economic incentives or rewards.

With a hybrid smart contract DR model, consumers would be incentivized through an automatically executing smart contract, which would analyze the measurements of the consumer's smart meter against predefined conditions. If analysis concludes that the consumer has complied with the conditions required by the ESE, then the client will be compensated immediately.

Oracles would be used to supply user consumption profile data on-chain. Retailers and DSOs can also work with other companies that want to promote sustainable consumption patterns as sponsors of the program, which may include cryptocurrency or NFT rewards. Ultimately, such incentives create a positive feedback loop where consumers pay lower rates on energy utilities and participate in sustainable practices while grid operators can better manage loads during peak hours and challenging conditions, avoiding or limiting the need for grid reinforcement in areas overloaded by the increasing penetration of local renewable resources, electric vehicles, and/or heating systems driven by heat pumps.

Grid Management

Energy grids contain a variety of variables, technologies, and participants that must be kept in balance in order to prevent outages and ensure grid quality. The fulfillment of these requirements is partly the responsibility of either the Transmission System Operators (TSOs) or the Distribution System Operators (DSOs), depending on national regulations and the coordination scheme in place between TSOs and DSOs.

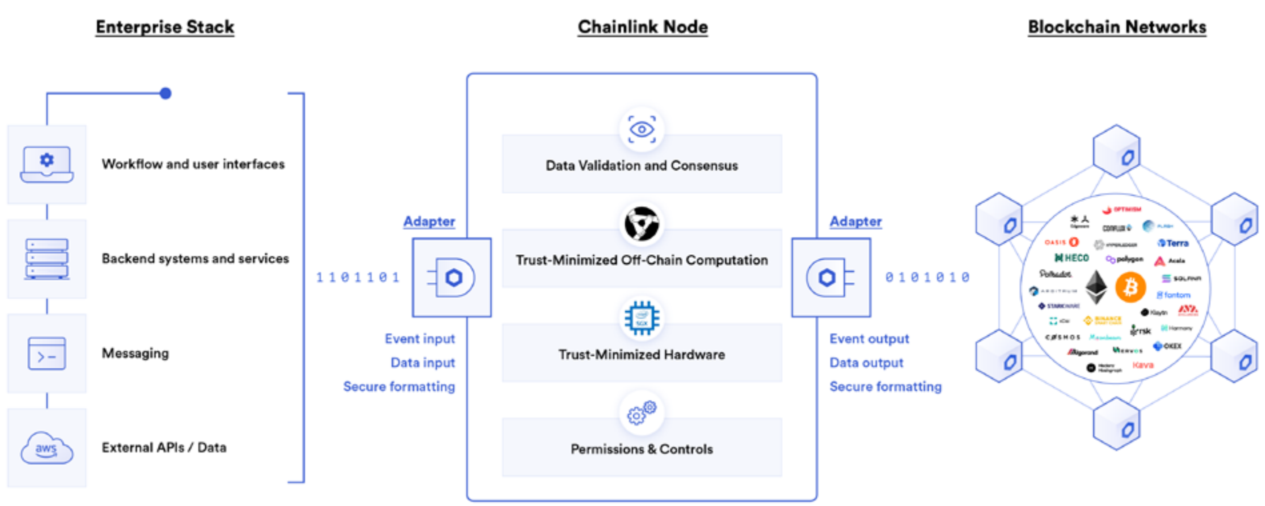
Ancillary services are generically defined as measures that must be taken by system operators to assure the security of supply to end consumers. For consumers, ancillary services are an integral part of the electricity supply. On the other hand, producers generate and sell electricity on the market, but can also provide flexibility via ancillary services to the system operator. Costs of ancillary services are covered by the system operator via power transmission charges or balancing energy fees, which then influences the retail electricity market price. In other words, all end electricity consumers are also consumers of ancillary services.

Ancillary services are divided into: voltage and reactive power control, black start of the power plants, island mode operation, frequency and active power control, and balancing energy. System operators manage a variety of systems that coordinate ancillary services at each of their different phases (contract, assignment, activation, settlement, and billing). The complexity of these processes, which involves coordination between several organizational systems and manual cross-checks, leads to high operative costs and drawn-out processes—industry pain points that can be solved for using blockchain technology.

A niche for the application of blockchain technology is marketplace implementation, particularly the contracting phase. Nowadays, there are many implementations of blockchain-based energy markets. For example, some local prosumer microgrids based on renewables have begun using blockchain technology for tracking and trading energy in peer-to-peer marketplaces, including projects like Powerledger and Energy Web. However, there are fewer implementations of markets for ancillary services. The INTERRFACE project, funded by the European Commission, will test a prototype for the TSO–DSO flexibility market.

Smart contracts are also specifically appropriate for managing the settlement of ancillary services. The settlement process is usually executed by a CCP (Central Counterparty Clearing House) on behalf of the system operator. The CCP is an organization that facilitates trading by bearing most of the credit risk of participants when clearing and settling market transactions. Blockchain networks are well-suited to replace or at least optimize the operation of CCPs, as they have already been implemented in the banking sector for expediting settlement. The benefits of managing operational tasks using smart contracts include reducing settlement risk and better tracking around the potential credit risks of counterparties.

However, using blockchain technology for grid management introduces additional complexity given it has to be integrated within existing management systems. Beyond feeding data, performing off-chain computation, and facilitating cross-chain communication, Chainlink's oracle infrastructure provides secure middleware that allows the existing backends of energy industry stakeholders to easily read and write data between any blockchain network. Oracles can perform tasks such as verifying activity recorded on a blockchain, triggering the execution of smart contracts, issuing cryptocurrency/digital asset payments, and documenting activity on a blockchain for historical records. Chainlink oracles are optimized as a gateway through which existing backends can connect to blockchains because they can support any blockchain, integrate with existing secure key management systems, and support various permission, privacy, and control settings.



Energy conversion contracts based on energy availability can be built as hybrid smart contracts. For example, professional weather data providers and DSOs can operate their own Chainlink oracle nodes to supply data on-chain used to trigger rewards/penalties.

Insights for Technical Decision-Makers

While wide ranging, the innovative energy applications above share certain assumptions about the optimal infrastructure when leveraging blockchain networks in combination with oracles. Below are three technical recommendations for securing, future-proofing, and maximizing the business impact of your hybrid smart contract system design:

1. Asset Tokenization: Utilize new or existing tokenization frameworks to track, monetize, and increase investment access to clean energy projects.

Transforming energy assets into blockchain-based tokens can help increase the utility of clean energy investments by making them more liquid and productive assets, as well as increase investment by enabling people around the world to more easily gain exposure to clean energy cash flows and equity. Tokenization also provides a transparent and immutable trail of ownership, leading to better auditability into the integrity and performance of clean energy projects.

2. Trusted Intelligence: Leverage oracles to validate real-world data and deliver it onto blockchains for accurately assigning value to tokenized assets and securely automating energy industry workflows dependent on external events.

Oracles are key to providing blockchains with trusted intelligence that verifies the state of events and systems that exist outside blockchains. Chainlink provides a flexible oracle framework for fetching and aggregating data from high-quality data providers, IoT networks, and third-party evaluators in order to access the impact of clean energy initiatives at both corporate and regional levels. Additionally, oracles provide a gateway for facilitating regulatory approvals within smart contract workflows without regulators having to run new infrastructure.

3. System Compatibility: Adopt secure oracle middleware to help ensure existing systems are compatible with any blockchain, enabling organizations to both monetize existing APIs and interact with counterparties' preferred blockchains.

Enterprises, governments, and other large institutions benefit from having a single, future-proof solution for writing and reading data to and from any blockchain. This substantially improves the ability for traditional systems to build a scalable blockchain strategy since developers only need to understand how the oracle middleware works when interacting with new chains as opposed to integrating with each chain separately. Secure oracle middleware also enables cross-chain communication should users want to deploy assets across chains based on internal strategies.

Ongoing Challenges

The possibilities hybrid smart contracts unlock for clean energy use cases are vast, offering the potential to increase investment, transparency, and accountability. However, there are still ongoing challenges that will require further research and development. The most notable challenges include:

- **High-quality data and open-source analytics**
- **Trust-minimization in event verification**
- **Industry collaboration and standards**
- **Identification of viable jurisdictions to pilot use cases**

High-Quality Data and Open-Source Analytics

Smart contracts are inherently data-driven instruments with automated execution, which means the quality and security of the data and computation used in their execution is critical to their correctness and reliability. While there already exists a wide variety of high-quality APIs that oracles can pull data from, there is still a need for more data relevant to clean energy processes, such as for measuring emissions and carbon footprints. There is also a need for open-source data aggregation and AI/ML algorithms that can be integrated within oracle networks as a means of generating trusted values from raw data or a complex set of variables, such as when generating green investment ratings and doing environmental analysis.

Trust-Minimization in Event Verification

Another key challenge is developing trust-minimization techniques that help prevent stale or malicious data from being used by smart contracts or corrupted computation. This will require more research and testing around various forms of cryptoeconomic security, reputation systems, device signing, location security, specialized hardware, integrated escape hatches, and outlier detection mechanisms. Once spotted, governance mechanisms need to be considered in order to successfully resolve disputes, either in real-time or retroactively.

Industry Collaboration and Standardization

One of the greatest overall challenges to blockchain technology adoption is getting industry-wide buy-in and establishing a set of mutually agreed-upon standards, particularly because blockchains facilitate multi-party processes on a single backend. Without getting the most relevant parties within a particular use case to participate, it will be difficult to tap into the value of hybrid smart contracts. Stakeholder collaboration will be important in order to develop standard legal frameworks for codifying smart contracts, configure oracle network parameters that all parties agree are secure to trigger automated value exchange, and put in place governance solutions for how to handle unexpected situations.

Identification of Viable Jurisdictions to Pilot Use Cases

The energy industry is highly regulated. The challenges of the energy industry require new solutions that explore new possibilities. The energy industry and the blockchain ecosystem should work together to identify viable jurisdictions to test and pilot some of these use cases for their long-term viability.

Next Steps for Energy Industry Stakeholders

Presented in this paper is a new backend framework for how to build clean energy solutions based on hybrid smart contracts. The basic premise is that blockchains can be used as a shared backend to store data and host applications that are more secure, reliable, transparent, and accessible to people around the world. Oracles should then play a foundational role in connecting the existing energy industry's datasets and infrastructure to blockchains, along with a variety of other key datasets, APIs, and systems needed to generate value on-chain. It's through oracles that green energy assets can be priced in DeFi markets, consumer consumption profiles can trigger financial reward systems, and RE contracts revolving around smart meters and weather data can be accurately settled in an automated manner.

It's from this foundation that many other clean energy use cases can be created and expanded on in the future, giving society a new and powerful infrastructure for transitioning to sustainable energy models, limiting the harmful effects of climate change, and facilitating positive environmental outcomes that are global in scale.

To work toward this new model, we have put together three business recommendations for energy industry stakeholders to support building a blockchain-based business model in clean energy.

Business Recommendations

1) Identify your use case.

Depending on your jurisdiction and business profile, one of the use cases outlined in this report might make sense as a way for your organization to start exploring the advantages of blockchain technology and the next phase of the energy industry. In other cases, the knowledge and insights shared in this document may help you identify other use cases that may not have been identified until now. Reach out to Tecnalia and Chainlink Labs to identify the most compelling use case for your organization.

2) Build a Proof of Concept (POC).

Working with such novel technologies as decentralized systems is always challenging, and even more in highly regulated sectors such as energy. The creation of a POC will help you get in touch with the technology and allow you to have tangible validation of the technology's application in your particular use case. POCs allow you to facilitate conversations with other stakeholders related to your use case, as well as with regulators.

POCs increase the return on investments made in highly innovative technologies by reducing risk and uncertainty. Therefore, build a POC to identify the possibilities and unforeseen details you did not consider. Polish and reiterate until your POC can become a pilot. Reach out to Tecnalia and Chainlink Labs to help you incorporate industry best practices.

3) Pilot a POC.

Test the POC by running it in production. Document the results in order to gauge its viability and learn how to improve it before productizing your solution. It is our goal to support as many blockchain pilots in the energy industry as possible. Contact our experts to find out how we can help you maximize the success of your pilots.

To find out how blockchains and oracles can transform your organization, reach out to our experts:

Chainlink Labs

Chainlink Labs
https://chn.lk/contact-us

tecnalia
MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE

Oscar Lage / Mikel Fernández
Cybersecurity and Blockchain Technology
https://www.tecnalia.com/

Contributors

Sergey Nazarov
Co-founder, *Chainlink*

Alex Preukschat
Head of GTM Leads, *Chainlink Labs*

Óscar Lage
Head of Cybersecurity and Blockchain, *Tecnalia*

Mikel Fernández
Senior Researcher in Energy and Applied Blockchain Technology, *Tecnalia*

Contact

Ari Chernoff
Communications, *Chainlink Labs*
press@chain.link

Eva Salgado
Marketing and Digital Communication, *Tecnalia*
https://www.tecnalia.com/

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