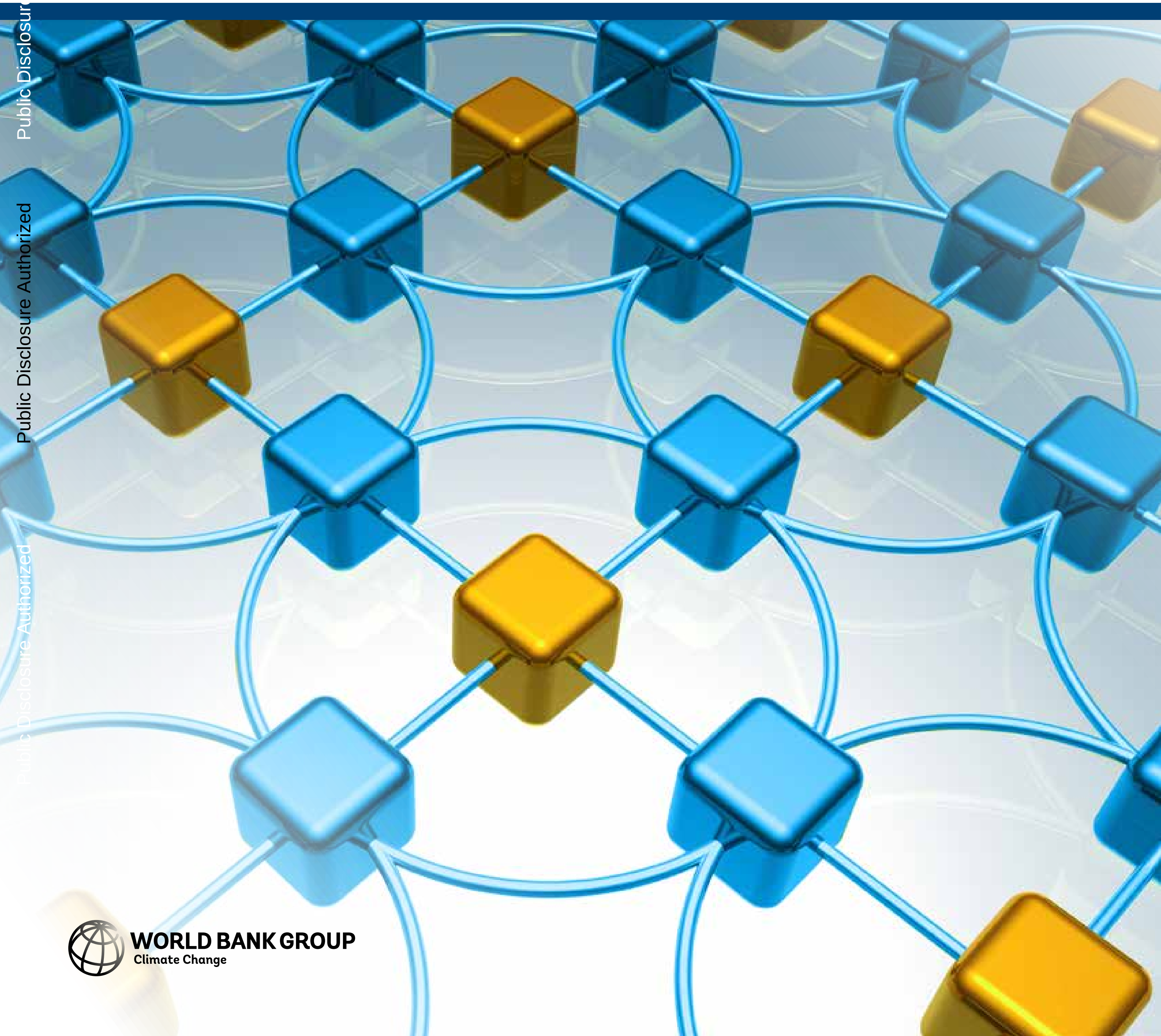
Blockchain and Emerging Digital Technologies for Enhancing Post-2020 Climate Markets



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Acknowledgments

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1. Executive Summary

Scientific consensus is that rapid and aggressive reductions in greenhouse gas (GHG) emissions are needed if significant climate disruption and irreversible environmental impacts are to be averted. The changes required necessitate large-scale investment and governments at all levels are responding with combinations of regulatory mandates, incentives and market-driven solutions. In this post-Kyoto Protocol era, there is a growing application of pricing mechanisms, especially markets, in multiple contexts to address mitigation of emissions. The new generation of climate markets is thus likely to develop as a network of decentralized markets, linking at regional, national and subnational levels.

The Paris Agreement (the Agreement) recognizes the heterogeneity of approaches. To foster higher ambition and sustainable development, and encourage large-scale financing towards the most effective mitigation measures, Article 6 recognizes that parties may engage in cooperative approaches, including the use of internationally transferred mitigation outcomes (ITMO) towards their individual nationally determined contribution (NDC).

Such a bottom-up framework promotes innovation and addresses jurisdictional priorities. Nevertheless, the growing diversity in the type, design, and scope of schemes does not encourage economic efficiency or the effective application of available financial resources. As such, an identified need is development of tools, services and institutions to foster and enhance this next generation of climate markets that accommodate such a "patchwork" of different domestic climate actions.

Different climate markets trade different units (assets), have differences in structure and governance, and rely on separate, centralized registries. The result is a multitude of schemes trading instruments within closed technological systems (with centralized registries) and differing rules, such as those associated with monitoring, reporting and verification (MRV). To facilitate larger, more liquid and resilient trading across heterogeneous climate markets, a new architecture is needed.

There is a corresponding need, also, for the capability to generate, manage, and harmonize information representing the outcomes of GHG mitigation actions across multiple industry sectors and governmental jurisdictions. The complexity of conducting transactions between heterogeneous climate actions across jurisdictions increases when additional instrument types (that is, not just emission allowances) are traded. Thus, the next generation of bottom-up climate markets must include mechanisms to address these differences so that the technological limits of an infrastructure based on centralized registries does not inhibit achieving the scale, heterogeneity, and functional complexity required.

At the same time, a rapidly evolving technological landscape presents opportunities for efficient and robust design and development of this next generation of climate markets, as well as risks, both in terms of failure to engage, or in failing to understand how to engage effectively. Blockchain, Big Data, the Internet of Things (IoT), smart contracts and other disruptive technologies hold out the promise of addressing the needs of new generation climate markets post-2020.

Blockchain, Big Data, the Internet of Things (IoT), smart contracts and other disruptive technologies hold out the promise of addressing the needs of new generation climate markets post-2020.

Blockchain, in particular, provides data sharing and transaction management elements well aligned with the requirements of climate markets. Blockchain is an implementation of distributed ledger technology (DLT), which, broadly, combines a distributed ledger (that is, a copy of the ledger is held by all network participants), public/private key encryption, and a decentralized infrastructure. The ledger is organized into blocks of information, each block containing information, such as a collection of transactions. Once there is consensus, the block is added to the ledger, which is immutable and accumulative. These characteristics support data integrity and security, while the distributed nature of the ledger promotes transparency.

There are also challenges associated with blockchain, both technical and non-technical. The former includes the fact that certain types of blockchain networks require high energy consumption (although these are unlikely to be suitable for climate markets), and potential issues with the speed and security for data transfers to and from blockchain applications, for example, with other digital systems.

Non-technical challenges include a paucity of understanding of the technology and its applications by many stakeholders. In particular, a challenge for adoption of the emerging digital technologies that must be resolved quickly is a culture change among regulators, standards developers, and policymakers. It is important to recognize that established interests and legacy systems could inhibit the adoption of digital technologies.

Significant factors characterizing the changing landscape of stakeholder needs, driving the transition from current to emerging technologies and practices, thus include the increasing diversity of regulations, MRV systems, climate assets, and values of mitigation outcomes, within and across jurisdictions; the increasing size and scale of post-2020 climate markets, as well as linkages with related climate actions and other markets; the expectation of new cross-jurisdictional trading arrangements (e.g., clubs, regional trading schemes, sectoral trading schemes); and greater financial flows and types of transactions, such as peer-to-peer and results-based finance.

It is concluded that digital innovations can help address these challenges firstly, through blockchain-enabled distributed ledgers that provide transparency and robust rule implementation via smart contracts; secondly, through collaborative governance systems that enable more efficient development of MRV standards structured as holistic systems of modular, compatible and extensible methods and rules; and finally, through smart meters and other devices associated with the IoT, combined with big data analytics, so as to facilitate the automated data flows necessary to harness the potential of blockchain technology in supporting new generation climate markets.

It is recommended that:

1. A roadmap for the implementation of blockchain and other emerging digital technologies in climate markets should be developed with the objective of making substantive progress on overall design, demonstration activities, and implementation. There should be close coordination with the technical policy agenda, both at the international level, for instance, in terms of the Article 6 work schedule and milestones, and at the national level. Specifically, these new technologies are most relevant in helping to address agenda items such as transparency, double counting, environmental integrity, and alignment with NDCs.

2. Additional research should be conducted, firstly, to clarify and elaborate how other types of emerging technologies, such as smart meters and other devices associated with the IoT and Big Data, can complement applications of blockchain that support new generation climate markets; and secondly, to confirm the technical, economic and legal underpinnings of the perceived advantages of blockchain applications in addressing the challenges that confront the new generation climate markets.

3. By way of extension of the research carried out under the preceding recommendation, pilot markets should be established to test research outcomes in “real world” environments. Such pilots should also serve to elucidate stakeholder understanding of how, in practical terms, the new technology will interface with existing technologies, will be embedded, implemented and operated.

2. Introduction

Market Provisions Under the Paris Agreement

Since its adoption in December 2015 by the 21st Conference of Parties (COP21), within the United Nations Framework Convention on Climate Change (UNFCCC), 175 countries to date have ratified the Paris Agreement ("the Agreement"). These countries have made commitments (NDCs), in some cases contingent on financing by developed countries, to limit or reduce their GHG emissions through a variety of measures including more significant deployment of renewable power, energy efficiency, land-use controls such as conservation of forests and grasslands, carbon pricing, and other measures compatible with each country's national circumstances and capabilities.

Even with full ratification of the Agreement by all 197 signatories, the aggregate effect is projected only to slow the rate of GHG emissions growth from the 24 percent increase, between 1990 and 2010, to an anticipated increase between 2010 and 2030 of between 11 and 23 percent.[1] Far greater reductions, approaching net zero emissions, will be needed after 2030 to meet the Agreement's goals of limiting the rise in global temperature to below 2° C, or ideally below 1.5° C.

To foster higher ambition and sustainable development, and also encourage large-scale financing towards the most effective mitigation measures, Article 6 of the Agreement recognizes that countries may engage in cooperative approaches, including the use of ITMOs towards their individual NDC. Unlike the Kyoto Protocol, under which emissions trading was restricted to developed countries, who also could purchase emission reductions generated by projects in developing countries, Article 6 of the Agreement potentially allows countries to contribute a diversity of climate actions with mitigation outcomes that can be transferred in any direction between cooperative Parties.

In this new, complex and diverse environment, this paper aims to examine emerging digital technologies and architectures that could be used to enhance and connect the heterogeneous climate actions across countries, thereby supporting post-2020 climate markets that facilitate the most cost-effective achievement of the highest possible ambition. Given the speed with which information technology, system architectures, domestic policy, and other relevant elements are developing, the roadmap laid out in this paper will likely continue to evolve significantly over the next few years.

Objective: Development of the Next Generation of Climate Markets

Today, there is a broad use of pricing mechanisms, especially markets, in multiple contexts to address mitigation of emissions. Market mechanisms have proven to be an economically efficient way to mitigate GHG emissions to deliver a specific objective (e.g., an emissions reduction target by a specific date). There are 40 countries and more than 20 cities, states, and provinces that have already established or will soon be implementing some form of carbon pricing system—either cap-and-trade or a carbon tax, including seven of the world's ten largest economies. Carbon pricing initiatives now cover approximately 13 percent of annual global GHG emissions.[2] There are jurisdictions engaging in cooperative programs (e.g., EU Emission Trading System (ETS), Regional

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1 UNFCCC, 2015, "Synthesis report on the aggregate effect of the intended nationally determined contributions," UNFCCC COP21, October 30, https://unfccc.int/resource/docs/2015/cop21/eng/07.pdf.

2 World Bank and Carbon Pricing Leadership Coalition, 2017, "2016-2017 Carbon Pricing Leadership Report," http://pubdocs.worldbank.org/en/183521492529539277/WBG-CPLC-2017-Leadership-Report-DIGITAL-Single-Pages.pdf.

Greenhouse Gas Initiative (RGGI), California-Quebec-Ontario[3]) but even connecting independent emissions trading schemes necessitates mechanisms to deal with different accounting rules, scope, pricing, offset eligibility, governance, complementary policies, and other key features. In reality, pricing mechanisms may take a variety of forms including as carbon taxes, schemes generating project-based credits, or certificates schemes for fuel switching or renewable energy. All these have the potential for integration in the broad mix of global "climate markets" post-2020.

While such a bottom-up framework promotes innovation and addresses jurisdictional priorities, the growing diversity in the type, design, and scope of schemes does not foster the most efficient and effective application of the financial resources available. Against this backdrop, the World Bank is working with governments, the private sector, academia and civil society to develop the tools, services and institutions needed to foster and develop the next generation of climate markets that accommodate such a "patchwork" of different domestic climate actions.

To ensure an efficient and robust design and development of this next generation of climate markets, it is critical to consider the rapidly evolving technological landscape. The goal of this paper is to provide background clarity to understanding the emerging technology trends that can support both the design and function of new climate markets from the bottom-up. While other technologies such as the IoT and big data analytics are mentioned (and elaborated briefly in Section 5), specifically, this paper will focus on the application of blockchain technology, and how it can work cumulatively with those other technologies.

To achieve the vision of a new generation of climate markets driving higher mitigation ambition, it is essential to first consider the current practices and technologies that have been used to support pricing and the challenges they present. Understanding the issues and gaps is essential to assessing the potential for emerging practices, technologies and architectural frameworks to harness the power of markets in delivering on the objectives outlined in the Paris Agreement.

3 California, Quebec, and Ontario established a linkage agreement that became effective on January 1, 2018.

3. Brief Review of Technologies and Practices in Existing Climate Markets

Current Data Collection

In spite of their differences, carbon pricing mechanisms around the world share common elements (e.g., data-driven emission caps and allowances, offset provisions, defined sectors),[4, 5, 6] and there are a multitude of MRV practices and technologies encompassing data collection, data processing, and data analysis that underpin these mechanisms. Since the 1990s, new technologies have enabled expanded MRV practices, from simplified organizational and subnational inventories and project-specific calculations to more accurate and comprehensive accounting, including, for example, continuous emission monitoring systems (CEMS), integrated life cycle assessment (LCA) databases, and cloud-based, tracking software systems for supply chains and programs of activities (POA).

More recently, innovative MRV practices and technologies utilizing information and communication technologies (ICT),[7] such as mobile and remote monitoring, are being advanced for transportation, distribution of household appliances and land use mitigation activities.

At a time when climate markets are gaining interest,[8] and advances in technological adoption and automation of MRV is occurring, nevertheless most climate change related MRV practices still involve manual processes that rely on disconnected data trails, spreadsheets, and static PDFs to achieve market and environmental integrity. These processes stand in contrast to the increasingly interconnected, highly transparent digital paradigm that is emerging globally,[9] constraining market integration and scalability.

Current Market Schemes

The Kyoto Protocol took a homogeneous approach to tradable units, which by definition were all equal to one tonne CO_2-equivalent GHG emission. The two most common types of tradable units in climate markets have been allowances and credits and following the Kyoto approach, these are generally set at a value of one tonne as well, although what it is a tonne of (e.g., CO_2, or CO_2–equivalent, or another GHG) will depend on the nature of the particular scheme.

The next generation of bottom-up climate markets must include mechanisms to address these differences so as to not inhibit reaching the scale, heterogeneity, and functional complexity that will be required.

4 World Bank, 2016, "Emissions Trading Registries: Guidance on Regulation, Development, and Administration," October 1, http://documents.worldbank.org/curated/en/780741476303872666/pdf/109027-WP-PUBLIC-12-10-2016-15-54-42-PMRFCPFRegistriesPosting.pdf.

5 Kossoy, Alexandre et al., 2016, "State and Trends of Carbon Pricing," World Bank, October 14, http://documents.worldbank.org/curated/en/598811476464765822/pdf/109157-REVISED-PUBLIC-wb-report-2016-complete-161214-cc2015-screen.pdf.

6 World Bank, 2016, "Emissions Trading in Practice: A Handbook on Design and Implementation," January 1, http://documents.worldbank.org/curated/en/353821475849138788/pdf/108879-WP-P153285-PUBLIC-ABSTRACT-SENT-PMRICAPETSHandbookENG.pdf.

7 Smarter2030, accessed September 30, 2017, http://smarter2030.gesi.org.

8 World Bank, 2015, "State and Trends of Carbon Pricing," September 20, http://documents.worldbank.org/curated/en/636161467995665933/State-and-trends-of-carbon-pricing-2015.

9 World Economic Forum, 2016, "Introducing the Digital Transformation Initiative," accessed September 30, 2017, http://reports.weforum.org/digital-transformation/introducing-the-digital-transformation-initiative/.

Allowances are issued under cap-and-trade programs where emissions within a defined boundary (e.g., country, industry sector) are capped. The allowances are issued to entities that are regulated within the boundary of the cap, to be surrendered by them against their emissions. Thus, the face value of an allowance reflects a unit of the amount the regulated entity can emit, rather than the amount of GHG emission mitigation brought about by a unit of that scheme.

Credits can encompass a variety of instruments, most notably GHG offset credits, renewable energy certificates,[10] and renewable fuel certificates (RINs).[11] As opposed to an allowance, a credit can reflect a unit of the amount of GHG emission reduction achieved, although depending on the type of credit, it may need to be converted into a base unit such as tonnes CO_2-equivalent: for example, renewable energy certificates may be expressed in KWh and need to be converted in order to be comparable with other units.

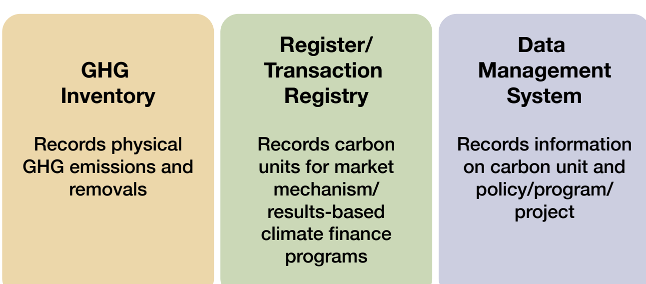
In any case where diverse pricing mechanisms are connected so as to allow transactions between them, in other words to provide for "fungibility" (or the mutual interchangeability) of their respective tradable units, there will need to be a mechanism to enable comparability. This is discussed further below.

Existing Technological Architecture

A functioning climate market requires rules, institutions, and infrastructure to enable proper market operation, transparent accounting and to ensure environmental integrity. A fundamental building block for market infrastructure is the accounting system(s) in which tradable units are held, transferred, retired, and recorded.

The World Bank has defined three types of emissions accounting systems (illustrated in Figure 1.)

Figure 1. Different Types of Emissions Accounting Systems Compared



Source: Emissions Trading Registries – Guidance on Regulation, Development, and Administration. World Bank, 2016.

The term registry can refer to a GHG emissions inventory, a list of project and program information, or databases with varying levels of functionality. While there are multiple considerations in the development, administration and regulation of GHG registries, there is a commonality in the underlying technological architecture of existing registries. Regardless of structure or level of complexity, existing transactional registries utilize a technological architecture based on a centralized ledger (or database) to support the transaction of units. There are good reasons for this design around central ledgers. Centralized ledgers are reliable and provide a system of record for transactions within a given scheme with clearly defined, tradable units.

Due to legal constraints, confidentiality concerns, institutional barriers, or other factors, there may be multiple registries or multiple centralized ledgers used within a single jurisdiction. Integrating multiple centralized ledgers requires not only new architecture (see Figure 2), but also overcoming constraints so as to facilitate the integration and transfer of relevant data.

For example, under California's Cap-and-Trade Program, details associated with an approved project may be stored across multiple websites each referencing serialized numbers and reports held in various places. The California Air Resources Board (ARB) summary for a project will be a set of serialized numbers held in the ARB central ledger, but these same numbers might initially have been held as a separate serialized set of numbers in a centralized register operated by another registry, such as the American Carbon Registry (ACR) and backed by a separate, PDF verification report.[12] In order for the original set of serialized numbers representing offsets issued under the ACR and held on the ACR registry to be transferred to ARB's centralized ledger, ACR must (a) "retire" the serialized numbers in its central ledger, (b) manually transfer the same numbers to ARB via spreadsheet or CSV to ARB, and (c) have ARB reissue a new, equivalent set of serialized numbers in ARB's central ledger.

An approach, such as in this example, may be sufficient within a given jurisdiction with appropriate governance and oversight. However, when the centralized ledgers are in different jurisdictions, standardized rules and oversight to enable transfers of units between those ledgers may not be available.

Figure 2 illustrates the systems supporting GHG data collection, aggregation, accounting, and reporting in jurisdictions usually organized around centralized databases. The databases have varying degrees of integration, depending on the jurisdiction and/or program considered. This is indicative of the system architecture in many jurisdictions with a market program in operation, each of which operates with its transaction registries at the core of its design. Each transaction registry will reflect the particular

10 United States Environmental Protection Agency, "Renewable Energy Certificates," accessed September 30, 2017, https://www.epa.gov/greenpower/renewable-energy-certificates-recs.

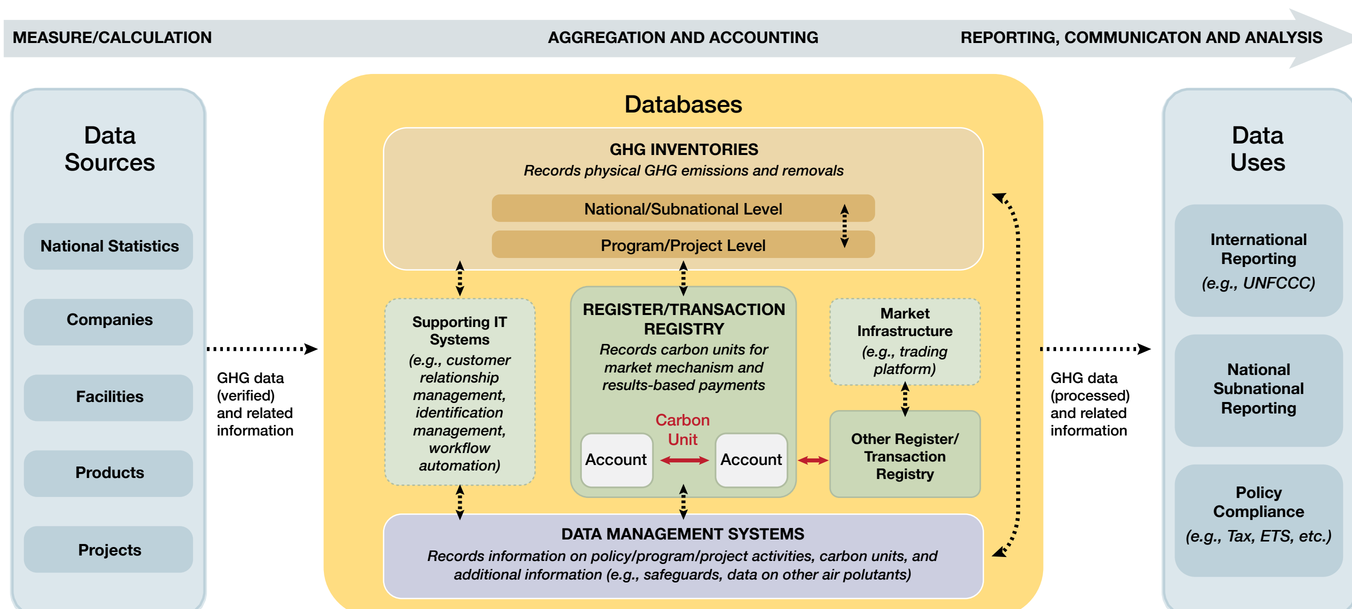
11 United States Environmental Protection Agency, "Renewable Identification Numbers (RINs) under the Renewable Fuel Standard Program," accessed September 30, 2017, www.epa.gov/renewable-fuel-standard-program/renewable-identification-numbers-rins-under-renewable-fuel-standard.

12 California Air Resources Board, "ARB Offset Credits Issued," accessed September 30, 2017, https://www.arb.ca.gov/cc/capandtrade/offsets/issuance/arb_offset_credit_issuance_table.pdf.

design and type of scheme of which it forms part, and thus will be technologically separate from those in other jurisdictions with different schemes, as will be the units, transactions in which are recorded in that ledger.

To address these differences, specific bilateral or multilateral agreements are required for any cross-jurisdictional transactions to occur. When the climate actions in the different jurisdictions are both emissions trading schemes, agreement as to the relative respective value of the units (and as to what those units/that value is a measure of) is necessary. The complexity of conducting transactions between heterogeneous climate actions across jurisdictions increases when additional instrument types (e.g., not just emission allowances, but also renewable energy certificates, RINs, offsets) are introduced. Thus, the next generation of bottom-up climate markets must include mechanisms to address these differences so that the technological limits of an infrastructure based on centralized registries does not inhibit reaching the scale, heterogeneity, and functional complexity that will be required.

Figure 2. The Transaction Registry in its Environment: Potential Connections and Interfaces



Source: Emissions Trading Registries – Guidance on Regulation, Development, and Administration. World Bank, 2016.

4. Architecture for New Market Design

As noted above, different climate markets trade different units (assets), have differences in structure and governance, and rely on separate, centralized registries. The result is a multitude of schemes trading instruments within closed technological systems (central-ledger-based registries) and differing rules—for example, those associated with MRV. There are examples of linked programs (e.g., the California-Quebec-Ontario cap-and-trade program) that aim to facilitate larger, more liquid markets by providing for cross-jurisdictional transactions, but the advent of more advanced technological approaches and designs that could provide more secure, efficient transactions of assets (carbon allowances, credits, or other carbon units) is changing the paradigm.

To facilitate larger, more liquid and resilient trading across heterogeneous climate markets, a new architecture is needed. There is a corresponding need, also, for the capability to generate, manage, and harmonize information representing the outcomes of GHG mitigation actions across multiple industry sectors and governmental jurisdictions. Advances in technology and standards, discussed in subsequent sections, allow conceptualization and design of systems in which information pertaining to different qualities of assets can be identified and tracked separately, but in connection with, other information concerning those assets, as they are transacted in the markets.

This delineation and tracking of separate value elements in the units is the key idea behind this new architecture.

Enhancing the Comparability and Potential Fungibility of Mitigation Outcomes Across Bottom-up, Heterogeneous Markets: Tracking Environmental Attributes of Various Commodities

Physical commodities such as oil, coal, palm oil, or soybeans can vary in value according to grade or quality or source location. Assets in climate markets (emission allowances, credits, renewable energy certificates or other units), although they are not natural commodities but a function of the policies and legislative schemes by which they are created, similarly may vary in value, in terms of the GHG mitigation in which they result. The variations will be a function of many factors, such as scope of the scheme, coverage, specific rules and scheme boundaries; the suite of policies and measures within which the scheme operates; or the jurisdiction's particular circumstances, capacity and ambition.

For different physical commodities, a digital asset can be created to represent and provide title to the commodity asset, as well as the multiple outputs (e.g., energy content) and outcomes (e.g., GHG emissions, energy access enhancement, poverty reduction impact) associated with its production and/or lifecycle.[13] The digital asset can be registered at the point of initial production to create a single, immutable record of the embedded attributes for that unit of the particular physical commodity.

Similarly, for tradable units in climate markets, information concerning value in terms of mitigation, or in relation to co-benefits such as energy access enhancement, or poverty reduction impact, can be identified as separate elements and tracked independently, while at the same time maintaining information concerning their source or identity. Blockchain technology can provide a digital mechanism for recording and tracking these separate streams of information associated with units, including when they are transacted across jurisdictional boundaries.

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13 World Bank, 2017, "Results-Based Climate Finance in Practice: Delivering Climate Finance for Low-Carbon Development," May 1, http://documents.worldbank.org/curated/en/410371494873772578/Results-based-climate-finance-in-practice-delivering-climate-finance-for-low-carbon-development.

This delineation and tracking of separate value elements in the units is the key idea behind this new architecture. As long as firstly, the integrity of the recording of the information is maintained, secondly, the information is aggregated in an accepted form of a climate information asset (or "climate asset"), and thirdly, the necessary mechanism is in place to convert climate assets to a common metric for comparability, such as their mitigation value, then transactions can take place across jurisdictions. Further, any type of market instrument (e.g., allowances, credits, RINs, renewable energy certificates), can be so transacted, provided such a metric (as, for example, mitigation value) can be applied. Furthermore, irrespective of how markets bundle and transact, the underlying information for the climate asset remains the same. This approach ensures market and environmental integrity by precluding double counting in relation to climate assets.

In this paradigm, ideally, new and existing markets (commodity markets, environmental and climate markets) might incorporate, or be configured in relation to, a universal ledger and trade the underlying attributes. Physically measurable events, represented by production and operational data, could be certified against new standards and aggregated into universally accepted assets. In the case of electricity, for instance, each MWh of power (derived from coal, natural gas, solar, hydro, or wind) could be accurately associated with its embedded impact within a given electricity market or, as in the case of renewable energy certificates, transacted separately.

This approach is dependent on the integration of production data (supported by appropriate technology, e.g., the IoT), the next generation of governance that supports digital approaches to MRV, larger scale data analysis to support MRV processes (e.g., big data analytics), and the broad application of blockchain functionalities in a dynamic market context at (or close to) real time. Such an integrated approach is unlikely to be possible through the combination of manual audit processes and multiple, disaggregated databases at the producer, auditor and/or market level. Further analysis of these emerging technologies and practices is included in Section 5.

The combination of blockchain technology, IoT, and the governance of the next generation of climate markets (discussed below), enables the creation of digital representations of commodities that can be used for existing markets and for transacting across climate markets (see Figure 3). The function of each layer illustrated in this vision of the new architecture in Figure 3 is outlined in Table 1.

Figure 3. Architectural Vision for the Networked Climate Markets

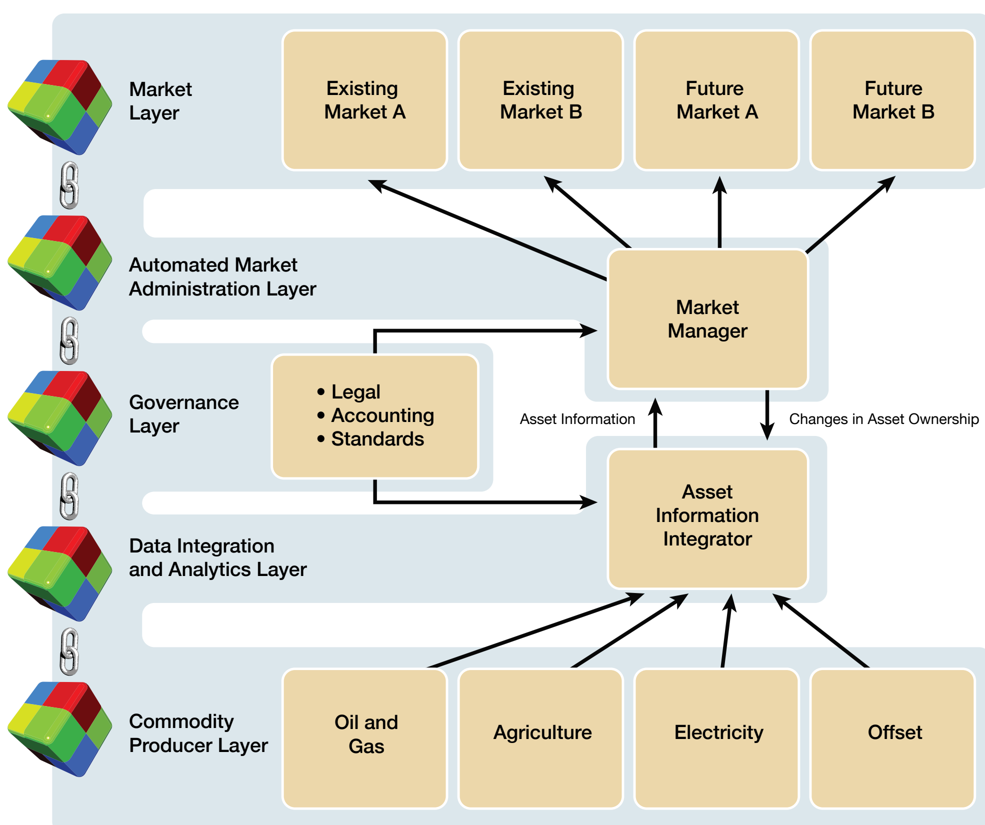


Table 1. Implementation Responsibilities for the New Generation of Climate Markets

Functional Layer	Role	Function	Examples
Commodity Producer	Event Data Provider	Foundational role in the ecosystem. The entities are primarily commodity producers and other sources of GHG emissions or emission reductions, subject to governance.	▪ Oil and gas producers, growers, refiners, power generators ▪ Capped emitters ▪ Offset project developers
Asset Information Integrator	Data Integration, Analysis, and Attribution Assignment	Gathers event data from event data providers. Data analytics and assignment of quantified and verified climate asset using consensus and peer-to-peer communication protocols (that is, blockchain). The role of "information provider" is also key to transparency. Increasingly, information asset providers will leverage IoT to obtain access to production data and Big Data as a secondary source of information for automated verification.	▪ Data platform operator ▪ Independent monitoring and verification body (although this role could be automated, depending on design)
Governance Layer	Legal, Accounting, and Standards	Governance will also be increasingly automated and can be administered through embedded logic derived from a combination of consensus-based, internationally-recognized standards, market rules, regulation, and auditing.	Standards organizations
Automated Market Administration Layer	Market Manager	Aggregates and structures climate assets using blockchain and makes them available to the market. This layer also records the provenance of the assets as they are bought, sold, and eventually retired.	Blockchain platform
Market Layer	Transactions	All manner of markets	▪ GHG allowances, RINs, renewable energy certificates, offsets ▪ Existing commodity markets (e.g., oil and gas, agricultural, electricity)

This simple "information service provider" architecture is the key to transacting across climate markets from the bottom-up. If deployed across multiple jurisdictions over time, the technological link between jurisdictions together with appropriate mechanisms to allow comparability of tradable units would enable direct transfers of mitigation outcomes and decrease the need for complex trading agreements across separate, centralized registries housing non-fungible assets. Over time, the foundational approach of generating climate assets could encourage standardization of MRV processes, enhancing the reliability of the mitigation outcomes of different instruments.

5. Blockchain as an Emerging Technology

The emerging and accelerating technological landscape holds promise in supporting the new generation of climate markets from the bottom-up in a post-2020 environment. Specifically, blockchain technology, trends referred to as IoT and Big Data,[14] and smart contracts should be considered in the future design of climate markets.

While this section examines the application of blockchain technology and smart contracts on post-2020 climate markets, more detailed analysis on other types of emerging technologies, such as IoT and Big Data, should be considered moving forward. Briefly, by way of background, the IoT is a very broad, constantly changing concept, for which one technical professional organization has sought to establish a baseline definition[15] that gives an all-inclusive definition that ranges from small, localized systems confined to a specific location to a large globally distributed system, composed of complex systems.[16]

The expression "Big Data" describes:

> "… *high-volume, high-velocity and/or high-variety information assets that demand cost-effective, innovative forms of information processing that enable enhanced insight, decision making, and process automation.*"[17]

These concepts are mentioned as technologies that can be complementary to applications of blockchain that support the new generation of climate markets and, as such, they are areas for future research. However, they are not considered here in more detail, the principal focus of this paper being on blockchain and its applications.

Blockchain

While secure chains of blocks of data,[18] incorporating cryptographic hashing,[19] have been defined and designed since the early 1990s, the first production implementation of blockchain technology was in a white paper authored by a person (or persons) using the pseudonym "Satoshi Nakamoto" in 2008.[20] The paper proposed an innovative peer-to-peer electronic currency called Bitcoin that would enable online payments to be transferred directly, without an intermediary. Bitcoin has garnered much attention, but the underlying technology, blockchain, is particularly relevant here.

Blockchain technology can synthesize and support the transaction of all types of emission-related data (e.g., facility level, projects, programs, quantified production, and life cycle attributes) in a shared, globally accessible environment.

14 There are also other aspects not necessarily falling within the concept of "Big" data, such as the inclusion of specified and necessary data points.

15 IoT, https://iot.ieee.org/definition.html : 'Towards a definition of the Internet of Things (IoT)' Revision 1 published 27 May 2015 (IEEE).

16 Ibid.

17 Gartner, 2012, https://www.gartner.com/it-glossary/big-data.

18 Haber, S. and W.S. Stornetta, 1991, "How to Time-Stamp a Digital Document," *J. Cryptology* 3: 2, https://doi.org/10.1007/BF00196791.

19 Bayer, D., S. Haber, W.S. Stornetta, 1993, "Improving the Efficiency and Reliability of Digital Time-Stamping," In: Capocelli, R., A. De Santis, and U. Vaccaro (eds), *Sequences II*. Springer: New York, NY.

20 Nakamoto, Satoshi, 2008, "Bitcoin: A Peer-to-Peer Electronic Cash System," November https://bitcoin.org/bitcoin.pdf.

Blockchain is just one possible implementation of Distributed Ledger Technology (DLT). Deloitte describes DLT as:

> "a type of database that is spread across multiple sites, countries, or institutions. It is decentralized in nature, eliminating the need for an intermediary to process, validate, or authenticate transactions. Each party (e.g., individual, organization, or group) is represented by their computer, called a node, on the network. Each node keeps its own copy of all transactions on the network, and nodes work directly with one another to check a new transaction's validity through a process called consensus. Each of these transactions is encrypted and sent to every node on the network to be verified and grouped into time-stamped blocks of transactions."[21]

Putting this another way, transactions are grouped into timestamped blocks. Blocks that have been chosen for adding to the chain by the consensus mechanism are sent to every node on the network.

Blockchain can be seen as enabling the collaborative creation of ledgers with properties and capabilities that go far beyond centralized ledgers and as having broad application for the transfer of value in human systems—including climate markets.

Financial services companies have shown early support for blockchain due to its ability to reduce risks and costs, although discretion and solutions are still needed for anti-money laundering (AML), as well as combating the financing of terrorism (CFT). The technology is increasingly being used in a variety of other sectors as well, including retail, manufacturing, telecommunications, media and entertainment, and healthcare.[22]

The basic premise of blockchain can be illustrated by comparing two types of transactions: (a) peer-to-peer; and (b) via a centralized hub (an intermediary or series of interconnected, trusted intermediaries).

Figure 4. Peer-to-Peer vs. Centralized Authority

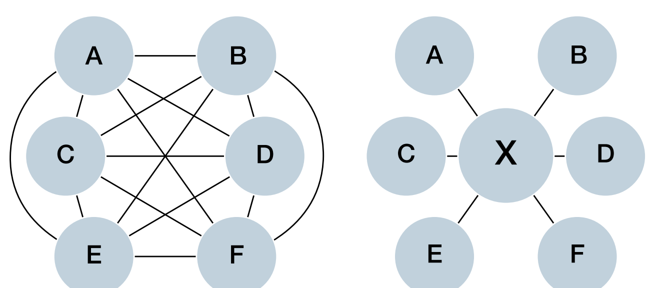


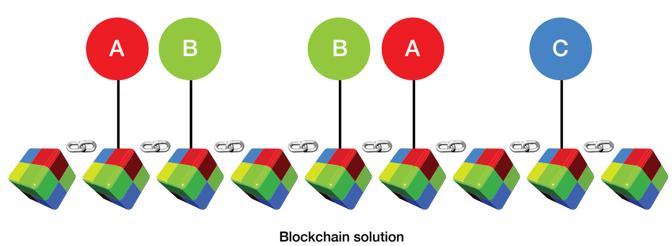
Table 2. Pros and Cons of Peer-to-Peer vs. Centralized Hub Networks

	Pros	Cons
Peer-to-Peer	▪ Low transaction cost ▪ No single point of failure ▪ Resiliency ▪ Distributed authority ▪ Innovation independence ▪ No large attack target	▪ Difficult reconciliation ▪ Intricate coordination ▪ Hidden vulnerabilities (double spending)
Centralized Hub	▪ Transactional security ▪ Reliability ▪ Single connection ▪ Reduced complexity ▪ Simplified reconciliation ▪ Universal system of record	▪ Single point of failure ▪ Higher transaction cost ▪ Influence consolidation ▪ Consolidated attack target

In order to transact money or anything of value, society has relied on intermediaries such as banks, governments, escrow, and settlement services to perform a range of services to build flexibility and trust into transactional processes.

There is no requirement for an intermediary in peer-to-peer transactions. However, intermediaries are important when making a digital transaction. Digital assets, like money in a bank account or credits on a registry, are electronic files that are easy to reproduce. This creates the "double spending" (or in the case of climate markets, a "double counting") problem.

Figure 5. Generic Structure of Blockchain Solution



As can be seen in Figure 5, blockchain technology combines the "pros" of peer-to-peer with the "pros" of a centralized hub listed in Table 2. The accumulative and immutable nature of the blockchain enables multiple parties to securely transact directly between each other without a central "trusted" authority.

Blockchain can be used in public (permissionless) or private (permissioned) networks. A public blockchain network is open to anyone who is interested in joining and participating in the network. On the other hand, a private blockchain network can only be joined by invitation and participants will be validated by the

21 Deloitte, 2017, "Project Ubin: SGD on Distributed Ledger," May 26, https://www2.deloitte.com/content/dam/Deloitte/sg/Documents/financial-services/sg-fsi-project-ubin-report.pdf.

22 PwC, 2017, "Briefing: Blockchain," May 18, http://usblogs.pwc.com/emerging-technology/briefing-blockchain/.

network initiator. Therefore, a private blockchain network is usually a permissioned network that places restrictions on the type of eligible participants and/or transactions.[23]

Blockchain in Climate Markets

In a post-Kyoto Protocol era, carbon-constrained world, GHG mitigation in all its forms increasingly has financial value. Blockchain technology can synthesize and support the transaction of all types of emission-related data (e.g., facility level, projects, programs, quantified production, and life cycle attributes) in a shared, globally accessible environment. A blockchain-based architecture can accommodate data that is captured automatically or manually to support an integrated network of climate markets over time without disruptive action. Recent publications by the University of Edinburgh present the advantages of blockchain in this context and make the case for the transition to "networking" of markets through the new architecture.[24, 25]

As noted in one of the Edinburgh publications, currently public and permissionless blockchain networks (e.g., Bitcoin and Ethereum) tend to use mining as a mechanism to reach consensus without a single entity dominating the network or participants being able to tamper with the distributed ledger. However, this mechanism requires significant computing power, and therefore, significant energy consumption. If the energy consumed is from high GHG-emitting resources such as oil and coal, then these types of blockchain networks may not be suitable for climate markets.

Thus, the proposed conceptual model advocates the use of permissioned networks that do not undertake mining, but rather reach consensus by agreement of the permissioned nodes, and allow for the flexibility to define user roles and privileges that will deliver the required functionality across different organizational and regulatory environments.

Blockchain's ability to collect an increased amount of data at a national and subnational level and make it available to every participant in a network may create concerns about data sensitivity. In some cases, a private blockchain network may be useful to address these concerns. However, this topic requires more in-depth consideration in future studies.

Transformative

In the context of transacting across climate markets pertaining to jurisdictions at various levels of technological maturity, DLT (hence blockchain) can be transformative:

- DLT does not require sophisticated IT infrastructure; it can support the migration to increasing levels of IT sophistication and functionality requirements over time. This is important, as global climate markets span jurisdictions with varying degrees of technological sophistication and also jurisdictions with existing, "legacy" infrastructure and processes.[26]
- The immutability of transactions supports *market integrity*, and the distributed nature of the ledger supports *transparency* in line with the METRIC Principles (see Section 6).
- The shared environment provides a common source of data to support the creation of new and/or the refinement of existing methodologies and governance systems.

Integrity

The current process for assuring integrity of mitigation outcomes for most tradable units requires a significant amount of manual verification by third-party, independent auditors. The "notary function" as a standard component of blockchain technology could be deployed to automate many aspects of existing verification processes. This would entail, for purposes of validation, verification, or issuances, creation of computer code logic to automatically require "proof of existence" of permits, certifications, standards, and/or other verification methods by referencing information that is publicly available on outside databases, as well as data from private sources (e.g., remote sensing, satellite imagery and encryptions, data providers, etc.) to ensure integrity of any and all digital assets.

Further, the assurance of marketplace integrity is supported through consensus across the ledger. A blockchain ledger is replicated across multiple member nodes and each location maintains its copy. Each member's copy of the ledger is updated based on new transaction data. Figure 6 illustrates a sequence of three transactions. In transactions #1 and #2, the data and signature information are properly validated by all three Member Nodes with identical hash values. However, the hash located at transaction #3 at Member Node 1 does not match the corresponding records at Member Nodes 2 and 3. Thus, this non-conforming record will be corrected by a consensus of the other member nodes.

23 Jayachandran, Praveen, 2017, "The difference between public and private blockchain," IBM, May 31, https://www.ibm.com/blogs/blockchain/2017/05/the-difference-between-public-and-private-blockchain/.

24 Macinante, Justin D., 2017, "A Conceptual Model for Networking of Carbon Markets on Distributed Ledger Technology Architecture," Edinburgh School of Law, April 10, http://ssrn.com/abstract=2948580 and [2017] 3 CCLR 243-260.

25 Jackson, Adrian, et al., 2017, "Networked Carbon Markets: Permissionless Innovation with Distributed Ledgers?" University of Edinburgh, July 4, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2997099.

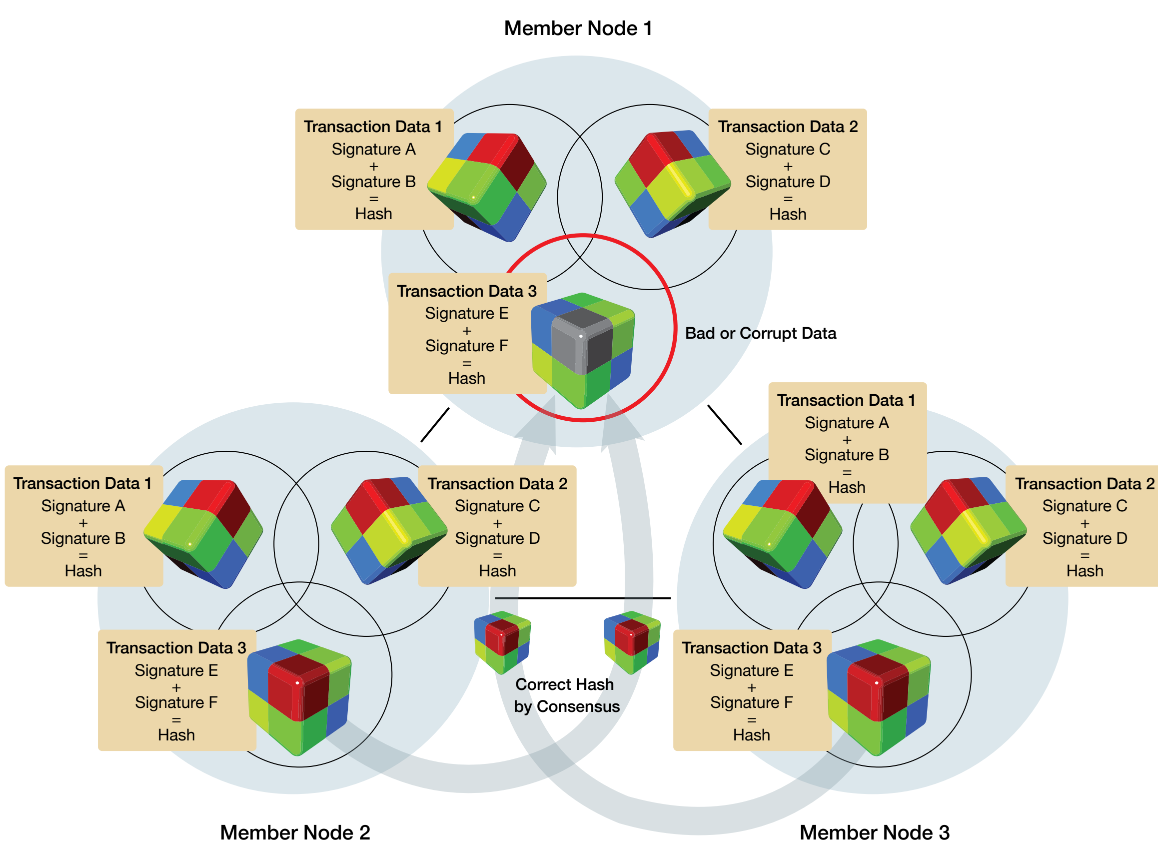
26 Technology diffusion considerations are described in detail in Jackson et al. (supra).

Smart Contracts

A "smart contract" refers to transactional terms and conditions embedded in computer code which allow automatic execution of the relevant transaction once precise conformity with those terms and conditions has been established.

In the context of transactions between climate markets, smart contracts have multiple applications. First, they can provide the mechanism for transactions between existing market schemes domiciled in different jurisdictions operating different registry infrastructures with differing instruments at the national, sub-national, or even industry level. This would only be the case if there were an independent assessment framework or frameworks to provide a common metric to value the differences between units of differences schemes, thereby affording those assets fungibility. This could include the internalization and execution of mutually agreed-upon equivalencies at the unit level by integrating independent assessment of mitigation actions and outcomes (for example through the Mitigation Action and Assessment Protocol (MAAP)[27]). Furthermore, smart contracts can be used to internalize governance (e.g., standards, policy, verification, data sources and commercial terms) between two or more jurisdictions or counterparties to prevent negative consequences (e.g., leakage), inhibit "bad actors" in the marketplace and ensure the environmental integrity of the market.

Figure 6. Illustrating the Hashing of Transaction Data Across Member Nodes and the Reconciliation of the Ledger via Consensus to Resolve Non-Conformities



27 World Bank, "Mitigation Action Assessment Protocol," accessed September 30, 2017, https://maap.worldbank.org/#/homepage.

6. How New Technology Aligns with Policy Frameworks

To support new generation markets post-2020, policymakers and stakeholders need the means to assess the suitability and effectiveness of direct, indirect, and other, more innovative, forms of cross-jurisdictional transacting. The METRIC Principles, outlined in Figure 7, provide a framework for such assessment.

Figure 7. World Bank METRIC Principles

M arket integrity

Ensuring that capital is allocated efficiently and avoiding disturbing the continued efficient function of carbon and related markets (such as financial and energy markets)

E nvironmental integrity

Enhancing the transparency and comparability of the value of the mitigation outcomes that are being transferred, based on key parameters such as robustness and ambition of the linked schemes

T ransparency

Transparent design to provide all stakeholders with a clear understanding of its rationale in order to generate support, and allow the free exchange of information

R ecognize ambition

Recognize effort sharing for a below 2° C target and avoid incentives to reduce effort

I nclusiveness

Facilitate and encourage more jurisdictions to join the scheme and promote greater international cooperation

C ost-effectiveness

Reduce the overall cost of mitigation, including administrative and transaction costs, and improve economic efficiency

Source: World Bank, 2016.

Building on the METRIC Principles

Further to the framework provided by the METRIC Principles, technology needs to be aligned with policy in designing effective connections between climate markets that can put the world on a path to achieve the ambitions in the Paris Agreement. Thus, it is important that technology design takes into account factors such as future growth (extensibility) and the need to accommodate increasing amounts of work (scalability).

Extensibility

Extensibility means that design takes into account future growth. The principle of extensibility in this context refers to practices and technologies for MRV and market instruments that can encompass multiple attributes, such as activities involving diverse Sustainable Development Goals (SDGs), as well as the ability to be applied in a modular and interoperable approach.

Existing environmental markets have overlapping and sometimes redundant requirements such as carbon emission caps, fuel switching (coal to natural gas), renewable energy targets, renewable energy credits, rebates for energy efficiency and electric vehicles, direct sector-specific regulatory controls, and carbon fuel-intensity limits. In addition, local public health and economic impacts may be difficult to account for in cases where a reduction in GHG emissions is the only metric. Accounting units and standards need to be extensible and interoperable for MRV at different levels of application, such as at the project-level and throughout the value chain level. Additionally, MRV standards and practices need to be modular to facilitate multiple environmental attributes and claims, such as the structure of the new Gold Standard for the Global Goals.[28]

28 Gold Standard, 2015, "Gold Standard For The Global Goals: Leveraging Climate Action for Greater Impact in Sustainable Development," www.goldstandard.org/articles/gold-standard-global-goals.

Scalability

Scalability means the capacity of a system or network to accommodate an increasing amount of work, or the potential to be enlarged in order to do so. The principle of scalability applicable in this context refers to practices and technologies for MRV and market instruments that can be efficiently applied to large-scale climate actions at local and regional levels such as supply chains and commodity markets. Heavy reliance on manual processes of current practices and technologies, described earlier, combined with multiple, dissociated and centralized registries inhibits the ability to scale market mechanisms and provide for markets to connect more globally. Thus, scalability is an important consideration to be addressed.

Governance Systems for Emerging Practices and the New Architecture

To operationalize and provide oversight for these new connected climate markets, underpinned by emerging technologies such as blockchain, new systems of governance will be required. With the adoption of the SDGs in 2015, and the Paris Agreement as the new global framework for addressing climate change, an unprecedented diversity of initiatives and innovative models integrating environment, society, and economy, with significant implications for the existing world of governance,[29] have been recognized. Though blockchain is a powerful technology to ensure rules are observed and applied, *how* to develop appropriate rules for the digital age and bottom-up implementation of the Paris Agreement is a separate issue. For example, connecting markets will require rules to govern trading of assets across multiple jurisdictions. The new architecture enabled by digital technologies requires a new set of operating rules such as smart standards and rules for smart contracts.

The next generation of governance will shape the application of digital technologies to support or automate activities such as data input and processing, quality assurance and quality control (QA/QC), audits and verifications, and standards collaboration. Digital technologies also enable greater participation and transparency for stakeholders into governance-related activities and documentation, while being able to balance necessary data protections.

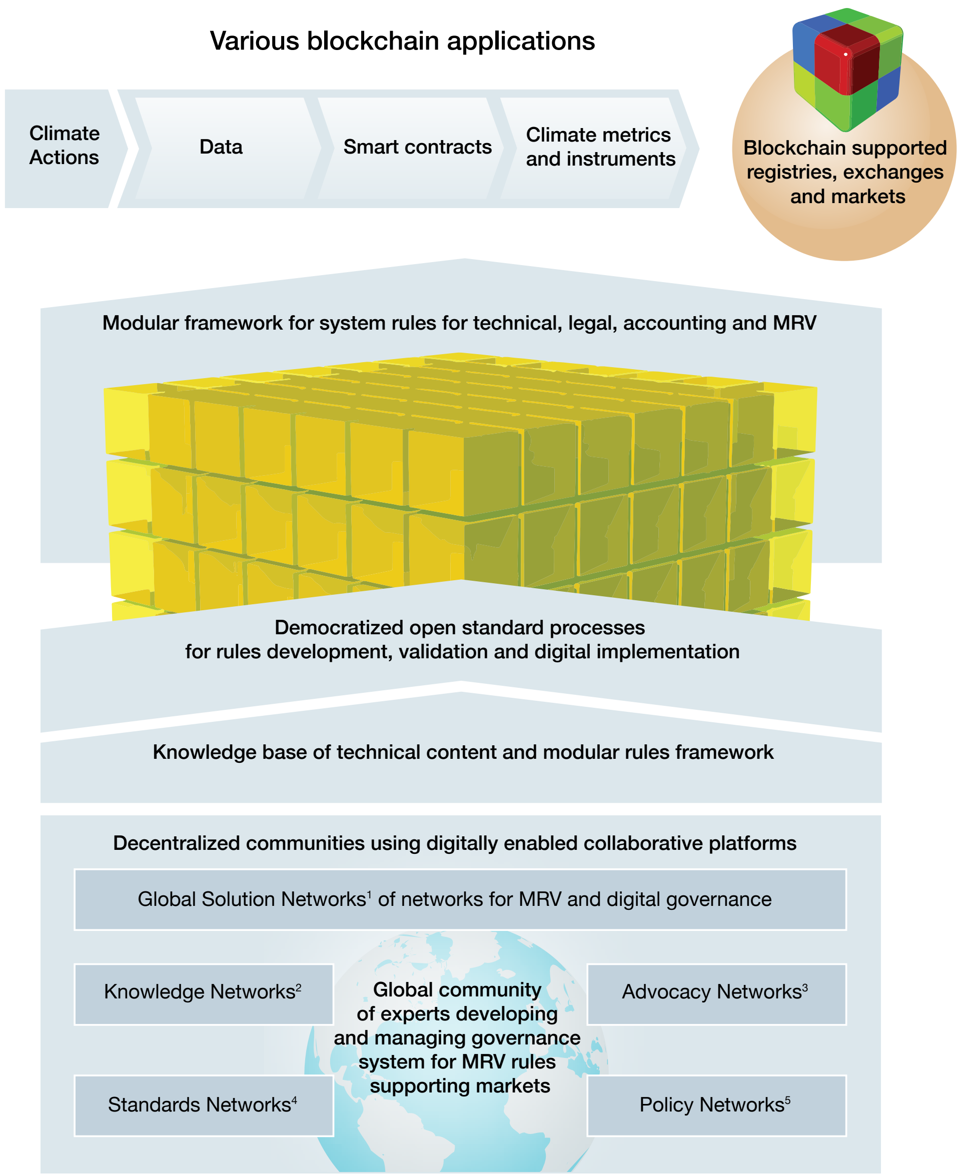
Though blockchain is a powerful technology to ensure rules are observed and applied, *how* to develop appropriate rules for the digital age and bottom-up implementation of the Paris Agreement is a separate issue.

Beyond these advances, additional innovations and enhancements may be needed for a next-generation governance system that will support a blockchain or digital platform. Elements that might be included in such are listed in the Appendix at the end of the paper.

A next generation of governance systems that provide greater agility and scalability will be essential to support the transformation of the economy and communities with new digital technologies like blockchain. The following figure illustrates an example of a governance system for blockchain applications.

29 For climate markets, "governance" generally refers to technical standards, methodologies, protocols, and guidance related to GHG quantification or assurance (i.e., MRV), as well as market rules and relevant legal, regulatory and institutional frameworks.

Figure 8. Governance System for Blockchain Applications Supporting the Next Generation of Climate Markets



1. Global Solution Networks (GSNs) are multi-stakeholder, self-governing networks enabled with digital technologies, such as the Blockchain Governance GSN.
2. Examples of knowledge networks addressing education and research are the Partnership for Market Readiness, NDC Partnership, Transparency Partnership, LEDS Global Partnership, GHG Management Institute, World Resources Institute, and Climate Ledger Initiative.
3. Examples of advocacy networks are the Carbon Pricing Leadership Coalition (CPLC), International Emission Trading Association (IETA), World Business Council for Sustainable Development, and Environmental Defense Fund.
4. Examples of Standards networks are the GHG Protocol, International Organization for Standardization (ISO), ISEAL Alliance, Gold Standard, American Carbon Registry (ACR), and Verified Carbon Standard.
5. Examples of Policy networks are We Mean Business, The Climate Group, 350.org, the Climate Reality Project.

Note: The initiatives listed in 1–5 are indicative and not intended to be exhaustive.

Challenges, Vulnerabilities, and Uncertainties for Blockchain

As with other digital technologies, there are technical challenges associated with blockchain, such as the fact that certain types of blockchain networks require high energy consumption to adopt financial applications ubiquitously[30] (and generally the association of the technology with bitcoin). There may also be issues with the speed and security of data transfers to and from blockchain applications, for example, with other digital systems such as those in the IoT. Currently, there are also only a limited number of blockchain developers (as of June 2017, the estimate is only 20,000),[31] yet a further consideration is the risk that the diversity of types of blockchain technologies could create incompatibility. Therefore, industry stakeholders will need to establish blockchain governance and standards to avoid the technology lock-in risk.

Among the widely-recognized, major, non-technical challenges is the lack of understanding of the technology and its applications by many stakeholders, for instance, in relation to issues of privacy on transactions, access to commercially-sensitive data, security of the digital assets, access to digital technologies (e.g., smart devices), and the costs and benefits of using blockchain as an alternative to conventional financial services. Additionally, stakeholders may lack understanding as to what the technology can and cannot provide, while intended recipients' capacity to implement also needs to be considered. The lack of, and the overarching need for, a governance system to support blockchain applications can also create uncertainty.[32]

In summary, blockchain technology has the potential to establish efficient peer-to-peer transactions without the need to have an intermediary (such as a bank, in the case of financial systems). However, new governance systems will be needed to ensure market and environmental integrity in a peer-to-peer environment.

Realizing the speed, agility, and scalability that distributed technologies offer will require new types of collaborative "distributed governance" systems that incentivize and motivate participants. Otherwise, the deployment of the digital technologies and climate actions necessary to achieve the goals of the Paris Agreement and the SDGs could be inhibited by bottlenecks associated with the application of technical governance (standards, protocols, methodologies) mechanisms in a digital context.

A next generation of governance systems that provide greater agility and scalability will be essential to support the transformation of the economy and communities with new digital technologies like blockchain.

30 As noted in section 5, public and permissionless blockchain networks (e.g., Bitcoin and Ethereum) can involve intensive algorithmic computations to confirm financial transactions, incurring high energy consumption. In contrast, permissioned blockchains (e.g., IBM Hyperledger) require lower energy consumption.

31 Redman, Jamie, 2017, "Experienced blockchain developers demand big salaries," June 8, *Bitcoin News*, https://news.bitcoin.com/experienced-blockchain-developers-demand-big-salaries/.

32 *Financial Times*, London, 2017, "Blockchain's Governance Paradox," July 14, https://ftalphaville.ft.com/2017/06/14/2190149/blockchains-governance-paradox.

7. Conclusions and Recommendations

This report has focused on the potential and issues associated with emerging digital innovations, principally blockchain and its applications, which could enable a new architecture to be designed and operationalized to support the next generation of climate markets and its related diversity of assets in the post-Kyoto Protocol era. While hurdles remain for digital innovations to become fully operational, such as the integration of digital technologies and governance systems to support a new digital paradigm, the benefits of the emerging technologies outweigh the limitations of the current technologies and practices.

Significant factors characterizing the changing landscape of stakeholder needs and drivers to precipitate the transition from current to emerging technologies and practices include:

- The increasing diversity of regulations, MRV systems, climate assets, and values of mitigation outcomes, within and across jurisdictions;
- A demand for more robust MRV systems corresponding to the needs of climate finance for ITMOs;
- The increasing size and scale of post-2020 climate markets, as well as linkages with related climate actions and other markets;
- The expectation of new cross-jurisdictional trading arrangements (e.g., clubs, regional trading schemes, sectoral trading schemes); and
- Greater financial flows and types of transactions, such as peer-to-peer and results-based finance.

Digital innovations can help address these challenges through:

- Blockchain-enabled distributed ledgers that provide transparency and robust rule implementation via smart contracts, to address the array of regulations and standards, and provide both the accountability and transactional efficiency required by regulators, investors, and market participants;
- Collaborative governance systems that enable more efficient development of MRV standards that are structured as holistic systems of modular, compatible and extensible methods and rules; and
- Smart meters and other devices associated with the IoT, combined with big data analytics, so as to facilitate the automated data flows necessary to harness the potential of blockchain technology in supporting new generation climate markets.

While considering how emerging technologies and practices can be deployed, it is essential to support different sectors and jurisdictions, proceeding at various rates and applying combinations of practices and technologies, to ensure a stable transition to a new global "disruptive technology" architecture. Investors and companies are already demonstrating enthusiastic bottom-up adoption of blockchain for financial and non-financial applications.

A key, non-technical, challenge for adoption of the emerging digital technologies that must be resolved quickly is a culture change among regulators, standards developers, and policymakers. It is important to recognize that established interests and legacy systems could inhibit the adoption of digital technologies. Culture change requires acceptance by these stakeholders of the need to support development of rules and standards via collaborative governance systems and to encourage greater innovation.

On the basis of the challenges and opportunities described in this report, the following recommendations aim to support a rapid phase of capacity building and implementation of emerging digital solutions.

Recommendation #1

A roadmap for the implementation of blockchain and other emerging digital technologies in climate markets should be developed with the objective of making substantive progress on overall design, demonstration activities, and implementation. There should be close coordination with the technical policy agenda, both at the international level, for instance, in terms of the Article 6 work schedule and milestones, and at the national level. Specifically, these new technologies are most relevant in helping to address agenda items such as transparency, double counting, environmental integrity, and alignment with NDCs.

Through its different initiatives building climate markets, the World Bank will support countries to make informed decisions and facilitate parallel development and alignment of policy and technology, so as both to address and resolve constraints, and to identify and leverage opportunities.

Recommendation #2

Additional research should be carried out, firstly, to clarify and elaborate how other types of emerging technologies, such as smart meters and other devices associated with the IoT and Big Data, can complement applications of blockchain that support new generation climate markets. Secondly, and perhaps more importantly, there should be research conducted to test and confirm the technical, economic and legal underpinnings of the perceived advantages of blockchain applications in addressing the challenges that confront the new generation climate markets (including, for example, the dichotomy between greater transparency and the need to preserve data privacy and confidentiality). It is important that this research be coordinated and dovetail with the agenda items focused in the roadmap, and dive deeper to examine key aspects such as the delineation and tracking of separate value elements of climate assets, the identification and application of common metrics for comparability, and the mechanics of transactions (e.g., including smart contracts) in these new generation climate markets.

Recommendation #3

By way of extension, pilot markets should be established to test research outcomes in a "real world" environment. The pilots might not only engage a variety of sectors and regions, but should focus on diverse elements, so as to better identify drivers of design aspects in the new generation markets, thus assisting in the prioritization of issues going forward. Such pilots should also serve to elucidate stakeholder understanding of how, in practical terms, the new technology will interface with existing technologies, will be embedded, implemented and operated.

On this front, the World Bank is working with a number of countries to identify a pipeline of climate actions where blockchain and other emerging digital innovations could be applied. By targeting different stages and layers of climate markets (e.g., asset generation and digitization vs. transferring and reporting; national vs. individual trading), the World Bank aims to effectively build countries' knowledge and capacity, address challenges and concerns, and thus create opportunities for timely blockchain developments in these countries. To facilitate this process, the World Bank — through its "Blockchain Lab" — has already started to engage and partner with leading technology companies, start-ups, entrepreneurs, innovators and other development organizations.

Appendix

Additional innovations and enhancements that may be needed for a next-generation governance system to support a blockchain or digital platform might include:

(1) A community of experts (e.g., standards development, management, application) using advanced online collaboration tools much more extensively;

(2) Standards structured so that specific parts can be updated more easily (as a "living document") without compromising the overall integrity of the document or governance system, in contrast to current practices with loosely-related static published documents;

(3) Standards linked to contextual content within a larger collaborative knowledge management (KM) system, including platform and user communities, for example:

(a) Links to the online knowledge base (e.g., a Wiki) and supporting research or work that has gone into the development of a standard,

(b) Links to "how to" guides, templates, data sources, and other resources to support the better implementation of a standard,

(c) Direct engagement with online expert groups (such as a mini social network of professionals) sharing expertise in Q&A forums;

(4) Standards designed to be more modular within a comprehensive framework,

(a) Modular standards made to be interoperable building blocks to reduce conflicting or duplicative requirements, as well as to avoid wasted resources and uncoordinated proliferation of standards; and

(b) Standardized or sectoral approach developed with a good balance of environmental integrity and the MRV cost;

(5) The specific content and methods in the standards that reflect the new digital, automated processes enabled by blockchain and IoT (in contrast to the largely manual or Excel-based current practices);

(6) The foundational governance system rules, e.g.,"the standard for developing a standard," and validation of new standards, that reflect more open, decentralized participatory or democratized collaboration models enabled by online tools, in contrast to the current practices that are more hierarchical and bureaucratic; and,

(7) Participants motivated to develop standards by a new economic model that is results-based, built on the outcomes of the use of the standards, in contrast to current practices in which strained expert volunteers experience "standards fatigue," or standards bodies sell copyrighted standards to recover the high cost of developing standards. For example, revenues associated with the carbon assets generated by the application of the standard(s) are shared directly with the standards participants as compensation. This approach is analogous to the blockchain model in which cryptocurrency "miners" are compensated according to a consensus validation of transactions on the blockchain.

Studies by the International Organization for Standardization (ISO) demonstrate standards have created significant economic value.[33]

33 ISO, "The main benefits of ISO standards", accessed September 30, 2017, http://www.iso.org/benefits-of-standards.html.

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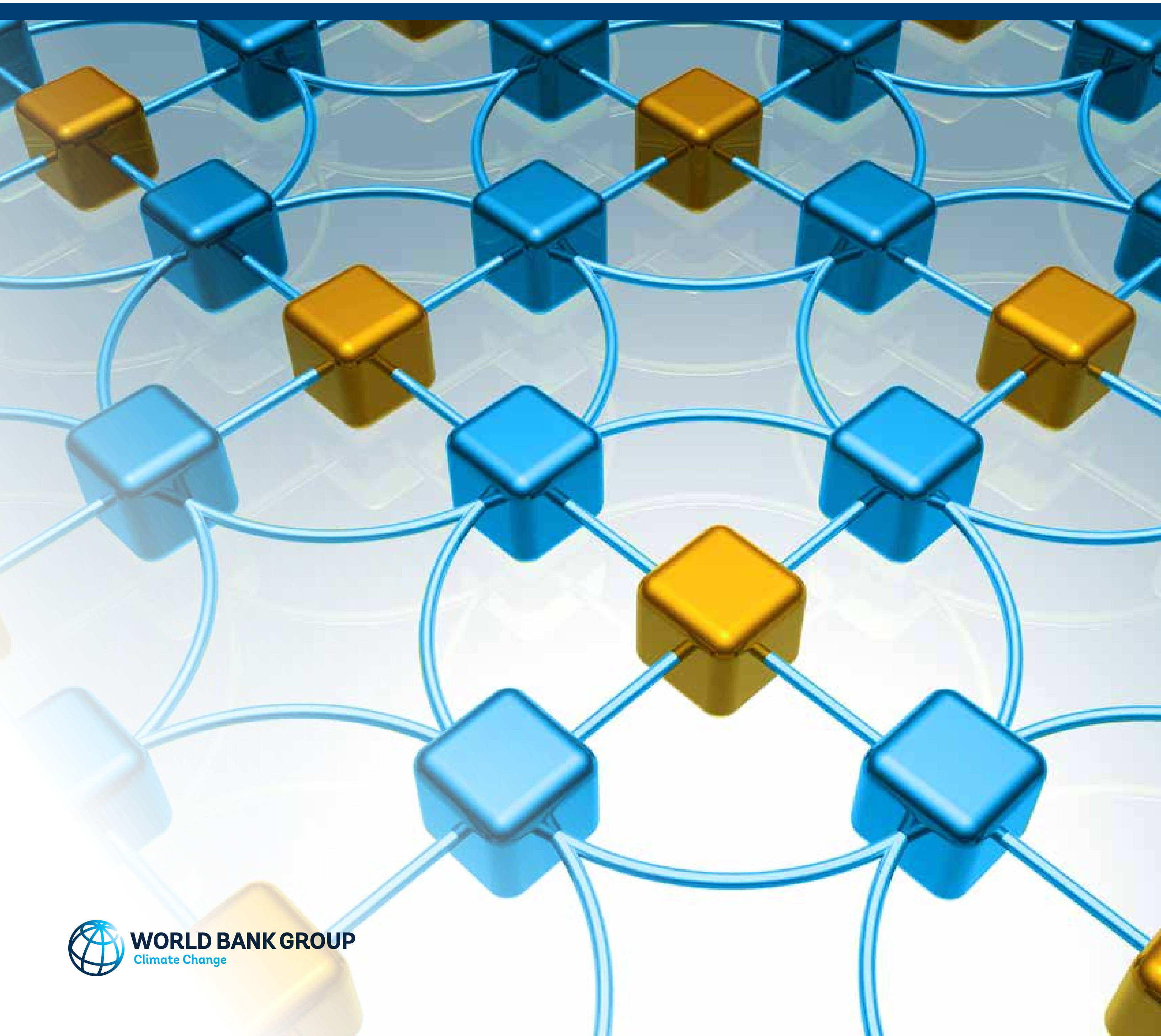
Acronyms

DLT	distributed ledger technology
ETS	Emission Trading System
GHG	Greenhouse gas
IoT	Internet of Things
ITMOs	internationally transferred mitigation outcomes
MRV	Monitoring, Reporting, and Verification
NDC	Nationally Determined Contributions
RINs	Renewable Identification Numbers
SDGs	Sustainable Development Goals
UNFCCC	United Nations Framework Convention on Climate Change



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