Chapter 13
Distributed Ledger Technology
and Climate Finance

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Abstract Enormous amounts of capital will need to be mobilized in the coming decades to drive the transition of our global economy toward climate neutrality. In recent years, the financial system started to move in a more environmentally sustainable direction, inter alia offering more green investment opportunities. Speeding up this process is inevitable if humanity wants to meet the Sustainable Development Goals (SDGs) and achieve the targets of the Paris Climate Agreement. Distributed Ledger Technology (DLT) may enable climate finance to effectively accelerate this transition toward sustainability. Inherent characteristics like security, immutability, transparency, and auditability make DLT a highly promising tool for climate-related use cases. However, the mainstream adoption of these digital innovations is still constrained by various obstacles, including technological and regulatory barriers, especially in the highly regulated finance sector. Existing digital divides between developed and developing nations further exacerbate these challenges. Based on these initial deliberations, this chapter shows how DLT can be used effectively for innovative climate finance. We first introduce the technology and discuss its sustainability as well as different possible DLT governance structures. Based on this introduction, we provide an overview of sustainability-related initiatives and networks linked to DLT. We review various DLT applications in Decentralized Finance (DeFi), asset management, Measurement, Reporting and Verification (MRV), tokenization, and other relevant fields. We conclude with an outlook on the role of DLT in climate finance and present recommendations for overcoming some of the remaining risks and obstacles.

Keywords Distributed ledger technology · Blockchain · Decentralized finance · Green finance · Sustainable finance · Climate finance · FinTech · Governance

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13.1 Introduction

Climate change and environmental degradation are the biggest challenges humanity is facing in the twenty-first century. Global emissions must be significantly reduced to limit the negative impacts of climate change, and to put our societies on a more sustainable trajectory that allows us to continue living on planet Earth. The Paris Climate Agreement sets the target of limiting global warming to “well below 2 °C” by the end of the century compared to the pre-industrial period. This transition of the predominant economic model requires considerable financial investments, together with the reorganization of the entire energy sector. Current development trajectories and political commitments do not suffice, as persistent financing gaps for climate mitigation and adaptation clearly demonstrate, including inadequate financing for sustainable energy systems (International Energy Agency 2020; UNCTAD 2020).

In light of the need for innovative climate finance, we set out to investigate the links between climate finance and technological innovation driven by distributed ledger technology (DLT). Climate finance denotes private and public financing related to banking, investment, and insurance that aims to support climate mitigation and adaptation actions. DLT has made major advancements since 2008, when the initial idea of a distributed ledger in the form of a blockchain emerged. In essence, the overarching term DLT refers to a group of protocols that enable the secure functioning of a decentralized digital database. Not only cryptocurrencies, which are based on distributed ledgers, but also DLT-based real-world applications have sparked interest across the board (Hughes et al. 2019). This is equally true for a broad range of applications seeking to support climate mitigation and adaptation (Dorflieitner et al. 2021). Relevant areas include the energy sector (Mengelkamp et al. 2018; Andoni et al. 2019), smart cities (Treiblmaier et al. 2020), and agriculture (van Wassenaer et al. 2021). Especially with regard to climate change mitigation, there is also increasing interest in tracking and monitoring of greenhouse gas emissions (Liu et al. 2019), carbon markets and trading (Kim and Huh 2020; Mandaroux et al. 2021), and indirectly linked efficiency gains, for example, through innovative supply chain management (Saberi et al. 2019). Most of these projects are still in their infancy but demonstrate the potential that the technology entails. However, DLT is not defined by a homogenous set of technical specifications. In addition, technical specifications are continuously evolving, which shows that DLT is not one monolithic technology, and that protocols and interoperability options develop dynamically. Accordingly, we systematically explore potential applications of DLTs in climate finance and show how this emerging technology cluster could accelerate the closing of existing financing gaps for climate change mitigation, adaptation, and sustainable energy systems (International Energy Agency 2020; UNCTAD 2020). Closing persistent financing gaps and boosting green finance will be pivotal for achieving the goals of the Paris Climate Agreement as well as the sustainable development goals (SDGs).
The sheer magnitude of the required economic transition becomes tangible by recognizing the rapid evolution of the green bond market in recent years. At the end of 2015, the total value of globally issued green bonds amounted to US $105 billion, which increased to US $1050 billion in 2020, of which US $269.5 billion was in the form of newly issued bonds (Climate Bonds Initiative 2021). However, the entire global bond market is much more substantial in size and had a market cap of US $128,300 billion in August 2020 (International Capital Market Association 2021). This means green bonds continue to represent a comparatively small share of the global bond market; they accounted for only 3.5% of total global bond issuance in 2019 (Ehlers et al. 2020). Fundamental shifts in capital allocation in line with global sustainability criteria are only beginning to emerge. However, a global survey of high-impact investors revealed that investors seek to double their sustainable assets by 2025 (BlackRock 2020). Evidently, there is an enormous demand for sustainable investments, which currently cannot be satisfied through available options.

The most commonly cited reasons for a lack of sustainable investments include high costs connected to the development and operation of green financial products; information asymmetry between participants, varying, indistinct, and non-standardized sustainability criteria; and lack of transparency in the sustainability certification process of an asset (Dorfleitner and Braun 2019). To illustrate the potential of DLT for addressing these key problems in climate finance, we first introduce the features and limitations of DLT, as well as different governance architectures and types of DLT-based systems. We argue that the effective use of DLT in climate finance will not only depend on trust, technological capabilities, and the actors involved in technology deployment or regulation, but also on initial design choices (Schulz et al. 2020). Based on our initial analysis of the technological potential and limitations, we then discuss the role of relevant sustainability initiatives and networks linked to DLT at the international, European, and national levels. In a second step, we review the use of DLT-based applications in decentralized finance (DeFi), asset management, measurement, reporting and verification (MRV), tokenization, and other relevant fields. We conclude with an outlook on the role of DLT in climate finance and present recommendations for overcoming some of the remaining risks and obstacles.

13.2 Distributed Ledger Technology

13.2.1 Technological Background

Distributed ledgers are able to store data across a network of participants and ensure data accuracy by finding a consensus among participants. This technological setup has developed into a variety of protocols that are built on different specifications. The majority of these protocols are based on blockchain technology (e.g., Bitcoin, Ethereum, Cardano, Solana, Litecoin, and Hyperledger) and a few depend on other structures of the ledger; for instance, on a directed acyclic graph (DAG) (e.g., IOTA
and Nano). Another important design choice across protocols is the structure of the consensus mechanism. By looking at the variety of approaches to create the basis for consensus, it becomes clear how diverse design choices have become: Proof of Work (PoW), (Delegated) Proof of Stake (PoS), Proof of Activity, Proof of Authority, Proof of Capacity, Proof of Elapsed Time, or Fast Probabilistic Consensus Algorithms (Kannengießer et al. 2020). However, initial design choices for a protocol could later be overruled by a majority of network participants. This will likely be the case for Ethereum where a part of the community, including the Ethereum Foundation, is currently preparing the Eth2 upgrades, which entail a transition from PoW to PoS (ethereum.org, 2020).

The most popular protocols also come with their own “native” or protocol tokens. These digital means of value exchange are commonly known as cryptocurrency. One of the most prominent cryptocurrencies is Bitcoin, which we will use as an example to better understand the functioning of DLT. In the case of Bitcoin, the blockchain-based distributed ledger is created by combining blocks of valid transactions into a chain of blocks, whereas each block is immutably linked to the preceding one. This chain is shared by the entire network, and each new block has to be verified by the majority of network participants. This act of finding consensus is carried out by solving cryptographic algorithms and requires a PoW from each participant, which in turn translates to computing power. Participants providing computing power are commonly referred to as “miners,” because they are mining new blocks by verifying bundles of transactions for which they are then rewarded with newly mined coins. Miners compete to be the fastest in adding a new block of transactions. In the case of Bitcoin, a lottery system is used to finally determine which block to attach, and thus to establish which miner is the “leader.” Together with the transaction fees paid by users who want to have their transactions executed, coin mining is a monetary incentive to keep the chain evolving. To break the system, an attacker would have to trick the majority of network participants, which would in turn require enormous computing power. Therefore, the aforementioned process leads to a secure, verifiable, trusted, and distributed ledger consisting of immutable, auditable transactions. Thus far, however, existing protocols have not yet been able to solve the “blockchain trilemma,” meaning that a protocol needs to sustain decentralization, security, and scalability at the same time. Common protocol design choices mostly sacrifice one property for the sake of the others. In the case of blockchain, this sacrifice is usually scalability, for which a solution is intensely researched (Zhou et al. 2020).

In June 2021, the developers of the IOTA protocol released an initial version of the development network “IOTA 2.0 DevNet (Nectar),” which is at the same time decentralized, secure, and scalable, according to the IOTA Foundation (2021). Instead of blockchain, the IOTA protocol relies on a DAG called “The Tangle” and targets the Internet of Things (IoT). To attach a new transaction to the DAG, each participant has to carry out a small PoW to confirm the validity of several other transactions. This means that the users themselves sustain the network, which scales according to its actual size, while coin mining is not necessary. The current IOTA protocol still sacrifices decentralization for the sake of security and scalability by having a centralized coordinator for the validation of value transactions. The
new protocol functions without central coordination. It adopts a novel consensus mechanism based on fast probabilistic consensus to sustain security (Popov and Buchanan 2021). Over time, protocol specifications will undergo rigorous testing and refining, finally leading to an upgrade of the IOTA main protocol. If successful, this step would mark a turning point in the DLT space, because the new protocol would be the first DLT to be decentralized, secure, and scalable, while also being free to use.

These examples of different base protocols illustrate how DLT systems can function as trust mechanisms based on consensus (Smits and Hulstijn 2020). Supplementary features such as smart contracts, decentralized Applications (dApps), oracles, non-fungible tokens (NFT), and asset tokenization either already exist or are in the process of being developed.

Smart contracts are based on code-based rules that the signing parties have agreed upon. Once a smart contract is initiated, it is immutable and follows the rules that were initially established. This process enables automated interactions between transacting parties. One use case are dApps that harness smart contracts and enable the application to run on a decentralized distributed system. Another connected feature are oracles that link the virtual DLT world with the real world by importing real-world data that can be used by smart contracts. One example is stock price data that is queried from a particular stock exchange, imported to the DLT system, and then utilized in a smart contract to trigger sell/buy orders once specific thresholds are reached. Another feature are NFTs, which function as digital representations for the ownership of unique items like (digital) art, collectibles, songs, videos, patents, or carbon credits that correspond to voluntary emission reductions or emission offsetting credits. Ownership is singular and tokens are not interchangeable (i.e., non-fungible), because each token is unique. Technically, an NFT is created by appending a transaction to a public ledger, including the cryptographic hash that certifies the uniqueness of a set of data and the ownership information. It is also possible to represent any kind of real asset, thus creating a unique digital representation of a physical or non-physical asset. With this process, non-fungible or fungible real assets can become liquid when they are broken down into digital shares. An example for a non-fungible real asset is a real estate investment of 30 million euro that is tokenized and split into 1000 pieces, thus creating investments of only 30,000 euro.

However, despite these promising technological features, current DLTs also come with a number of limitations, and often with technological sustainability issues. The most prominent issue is the high energy consumption required to conduct PoW for some blockchain-based protocols. On 22 November 2021, one single transaction in Bitcoin (Ethereum) required around 1985 (197) kWh, which amounts to an annual electrical energy use of 198 (91) TWh for the entire network, making it comparable to the power consumption of Thailand (Philippines) (Digiconomist 2021). Using a digital technology with such high levels of energy consumption to tackle climate change would indeed be self-contradictory. Furthermore, blockchain-based protocols are still limited by the scalability issue. Today’s networks could reach their maximum throughput due to a rising demand for transactions and soon become congested, which would result in rising fees for processing transactions and delays in transaction
processing. Transaction fees are a limiting factor in general, but in particular because of their great variance over time: in the first half of 2021, they alternated between $4.5 ($3.1) and $63 ($72) per transaction for Bitcoin (Ethereum) (YCharts 2021). However, not all DLTs have issues of high energy consumption and transaction fees; for instance, PoS utilizing blockchains or DAG-based protocols. In addition, protocols facing those issues are working on solutions or are already preparing to integrate them; for example, Ethereum with its Eth2 upgrades. Another noteworthy technological limitation is the lack of interoperability between different protocols, which may limit their functionality.

Apart from these technological limitations, we also regard politicization and a general lack of trust in the technology sector as obstacles for the application of DLT. The digital sphere is barely regulated and is sometimes seen as a lawless space. In addition, interested companies are often not able to utilize DLT because of non-existent regulation; for instance, the regulation of cryptocurrencies. Another important regulatory issue is the immutability of transactions, which concerns privacy and security challenges related to the EU General Data Protection Regulation (GDPR), and especially Article 17 GDPR, which outlines the so-called right to erasure (right to be forgotten). In this regulatory environment, only a limited subset of potential applications can be executed effectively. However, an enabling regulatory environment that creates legal security is essential for broad adoption of DLT.

Considering the opportunities and limitations of DLT, it is important to note that the appropriate design of DLT systems is crucial for users as well as application operators. Following Schulz et al. (2020), we differentiate DLT systems into four different types: (1) public-permissionless ledgers, (2) public-permissioned ledgers, (3) private-permissionless ledgers, and (4) private-permissioned ledgers. Table 13.1 summarizes these four different types of DLT-related governance systems.

The embeddedness of DLT in real-world legal and regulatory structures shows that the use of DLTs is directly linked to contextual circumstances and questions of governance. The term on-chain governance describes the set of rules determined by the technical code of a given DLT application. This type of governance determines, i.a., the consensus mechanism, decision power, participants in the network, the reward system, and what information to record. Therefore, a key element when developing a DLT application is the design of its governance structure to create a secure environment and curtail future structural complications that may disincentivize its use. Simultaneously, off-chain governance in the “real world” must enable the effective transnational use and standardization of DLT applications, while addressing existing risks related to, inter alia, cybercrime, privacy, data use, or legal compliance.

Off-chain governance, more specifically, can be further distinguished into the governance of the digital sphere, on the one hand, including Internet and financial regulation. On the other hand, off-chain governance in this context can also refer to governance through the digital sphere, for example, by issuing official digital identities, currencies, or certificates. Accordingly, the effective use of DLT crucially depends on initial design choices, both on-chain and off-chain, for specific governance systems. These choices are inherently political, especially in the case of off-chain governance, and presuppose rigorous assessments for each application to select
### Table 13.1  Distributed ledger technology systems

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<tbody>
<tr>
<td>Public access to ledger</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Open participation to verify and add transactions</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Governance</td>
<td>Fully distributed</td>
<td>Partly distributed</td>
<td>Partly distributed</td>
<td>Fully centralized</td>
</tr>
<tr>
<td>Token required</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Examples</td>
<td>Bitcoin, Ethereum, Cardano, Solana, Litecoin, IOTA</td>
<td>Ripple</td>
<td>LTO Network</td>
<td>Hyperledger Fabric</td>
</tr>
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*Source* Schulz et al. (2020)
the most suitable DLT. This means that DLTs are useful digital tools for tackling specific problems in climate finance such as the need for standardized and transparent monitoring and evaluation, but not a stand-alone technological solution for key political issues in the field of climate finance.

13.2.2 Sustainability Initiatives and Networks

The transfer of sophisticated technology to real-life applications is a challenging task in general, particularly due to the technical complexity of DLTs. Various initiatives and networks have been formed to introduce and promote the potentials of DLT with the aim to foster real-life applications. We discuss the role of three selected initiatives and networks at the international, European, and national levels to illustrate the relevance of DLT for sustainability and climate action at different regulatory and governance levels.

At the international level, the Climate Chain Coalition (CCC) was formed in 2017 by various stakeholders with a focus on utilizing DLT and related digital solutions for mobilizing climate finance and fostering effective MRV to scale climate actions for mitigation and adaptation. The open global initiative involves more than 170 members ranging from research institutions and other initiatives to private sector companies (Climate Chain Coalition 2021). Coalition members self-organize in various teams that deal with topics such as education in a specific region, the development of concrete applications, and research collaboration. The CCC maintains close ties with multilateral organizations such as the United Nations Framework Convention on Climate Change (UNFCCC) or the World Bank. This reflects the coalition’s approach of applying DLT to tackle global issues such as climate market challenges and product traceability in supply chains, especially within multilateral organizations. Because of diverse national circumstances, it is useful to have an international network to exchange knowledge, learn from each other, and even transfer ideas that might not be applicable in one specific country to another setting where they might work well. In addition to existing and potential real-life applications, the engagement of multilateral organizations with DLT also helps create trust between national governments, and might even reduce global knowledge asymmetries.

At the European level, the EU Blockchain Observatory and Forum (EUBOF) was launched in 2018 based on an initiative from the European Parliament. It is funded by the European Commission (2018). EUBOF is tasked to identify and observe global trends in the DLT sector, foster education and knowledge dissemination, create a forum for knowledge exchange, and to accelerate the application of DLT in the EU by providing policy recommendations concerning regulatory questions (EU Blockchain Observatory and Forum 2021). The formation of this initiative is in line with the EU’s aim to become a global leader in blockchain technology as outlined in the European Blockchain Strategy (European Commission 2021a). This is also reflected by recent regulatory proposals; for instance, the “Regulation on Markets in Crypto Assets (MiCA) and the Regulation on a Pilot Regime for Market Infrastructures based on
Distributed Ledger Technology (DLT)’’ (European Commission 2020). Within the EU, EUBOF plays an essential role as a low-threshold space for knowledge exchange across the Union. Compared to the CCC, EUBOF has been proactively initiated by policymakers and is primarily focused on knowledge creation and dissemination, and less on knowledge adoption. This approach creates institutional credibility and lowers the barrier for EU member states who have not yet explored DLT to access relevant knowledge. EUBOF has no particular focus on the links between DLT and climate change but has dealt with related sustainability issues in different formats.

In addition, DLT use is also facilitated by national-level initiatives such as the Dutch Blockchain Coalition (DBC). The DBC was founded in 2016 by partners from the Dutch government, knowledge institutions, and industry to serve as a catalyst and facilitator for socially accepted DLT applications. The work of the DBC is based on a broad action agenda that encompasses the investigation of DLT capabilities, (potential) DLT legislation, as well as research and training programs. The DBC focuses on digital identities, the definition and creation of “good conditions” under which DLT-based applications can be used, and the formation and realization of a human capital agenda (Dutch Blockchain Coalition 2021). The coalition’s principal task is to establish the social, legal, ethical, and economic conditions under which DLTs can thrive. In this context, standardization, norms, and governance are pivotal, together with international collaboration. The DBC also functions as a network for knowledge distribution. Since 2019, the focus has been placed on specific use cases and experimental research in the fields of self-sovereign identity, logistics, educational certification, pensions, compliance by design, and mortgages.

13.3 DLT-Based Applications in Climate Finance

In line with our research approach, we focus exclusively on DLT applications in public or private financing that are designed to support climate mitigation, adaptation, and/or sustainable energy systems. Relevant applications can be found in the banking, investment, and insurance sectors, where the unique features of DLT are used to increase efficiency and reduce risks for involved parties. Accordingly, this section engages with a variety of DLT applications in different fields of public or private financing. Each field is briefly introduced and concrete use cases with a link to climate finance are presented. Relevant fields include (13.3.1) Decentralized Finance (DeFi); (13.3.2) asset management; (13.3.3) Measurement, Reporting and Verification (MRV); and (13.3.4) tokenization, together with (13.3.5) other community-oriented approaches.
13.3.1 Decentralized Finance

Since 2020, DeFi has gained popularity around the world, reaching an all-time high of US $112 billion in locked value by November 2021 (DeFi Pulse 2021). DeFi requires a DLT protocol that is public and comes with smart contracts (e.g., the Ethereum protocol), thus enabling the creation of dApps on top of the protocol. This general setup enables peer-to-peer (P2P) financing and complex financial applications by combining multiple dApps. The decentralized and open-source nature of these apps bypasses classical financial intermediaries. Yet, decentralization also has its downsides such as insufficient regulation and a lack of deposit insurance, two measures that would normally reduce risks for the customers of financial intermediaries. Such issues of accountability directly relate to the governance of DeFi products, which can be categorized in three different forms (World Economic Forum 2021).

First, if a service is implemented and exclusively controlled by the operator of the service, centralized governance is present. Decentralization of governance can be introduced into the system by integrating a governance token that represents voting rights on governance questions. Second, if token holders only have limited voting rights and can merely govern certain predetermined parameters while the developer(s) and/or operator(s) still hold great power, this is called partially decentralized governance. Third, fully decentralized governance can be established through the formation of a decentralized autonomous organization (DAO), which specifies the rules for the interplay between governance token holders. Often, the aim of developers is to move from a centralized to a decentralized governance structure as the project matures. In the following, we take a closer look at several popular types of DeFi services to better understand the status quo in the sector. The first important type of service concerns stablecoins, which address the issue of price volatility in cryptocurrencies. The idea is to back-up a token with some collateral to create a stablecoin. Collaterals can be fiat money, commodities like gold, crypto assets, or a combination of several of them. Another approach is to use algorithms that autonomously carry out specific actions to stabilize the price. Stablecoins have been pivotal for the evolution of DeFi because a stable currency is critical for financial products. Second, decentralized exchanges (DEXs) facilitate direct exchange of currencies between users, for example, cryptocurrencies or classical currencies. Third, P2P cryptocurrency lending/credit platforms directly connect lenders and borrowers to each other. The content of lending agreements has no limit, so that for instance, short-term (flash) loans become feasible. Such platforms enable direct interactions between savers and borrowers. Fourth, decentralized prediction markets enable participants to bet on the outcome of future events. Agreements are translated into smart contracts that use oracles to decide on the final outcome and trigger corresponding actions. All these types of DeFi services have been technology front-runners so far, but more and more additional services like derivatives or insurances are offered. Figure 13.1 illustrates the general setup of DeFi comprehensively.

DeFi offers the potential to democratize the financial sector by bypassing intermediaries, and by equalizing access to high-return financial products. In addition,
it can enable access to climate finance and insurance for the unbanked. Thus, DeFi can provide people with financial tools to shape their surroundings; for example, through access to external investment for local renewable energy projects. Such projects often face frictions in local finance markets, which can now be dissolved by borderless DeFi. Classical use cases in climate finance include donations or philanthropic investments, which often flow from industrialized countries to projects in developing countries. To improve the trust of donors, the traceability and auditability characteristics of DLTs are harnessed.

**GiveTrack™**: Funded by the non-profit organization BitGive, this blockchain-based donation platform for non-profits provides transparency and accountability to donors and enables cryptocurrency donations. Financial information and direct project results are shared in real-time with donors. The majority of funded projects are small in scale and some projects are linked to climate actions.

**TruBudget**: Initiated in 2017 by the German development bank KfW, the open-source Trusted Budget Expenditure Regime workflow software makes the implementation of donor-funded projects more transparent and collaborative by using a “logbook” approach. By using private blockchains, all activities are securely and traceable documented, which facilitates relationships between donors, fund managers, and project implementers. This setup allows public investments to be carried out more securely, transparently, and effectively. One use case is the Amazon Fund, which uses donations for efforts to prevent, monitor, and combat deforestation.

Another important application are P2P lending services that offer direct links between lenders and borrowers. Although the use of DLT is not mandatory to enable such services, it can be of benefit to reduce service costs, increase investor trust, and enable new types of services. One example for the latter are flash loans, which are instant and collateral-free loans that have to be paid back within a short period. Most DeFi P2P lending platforms do not focus on climate-related loans and offer standard
loans for individuals and businesses. However, there are established projects that have built platforms that explicitly focus on climate action and sustainability-related investments.

**Sun Exchange**: Founded in 2015 with the aim to overcome hurdles in financial markets that impede the exploitation of solar energy in emerging countries, the Sun Exchange is a P2P solar leasing platform that links investors with potential solar energy projects. Funded solar cells are leased out to users like schools or local communities. The company integrates Bitcoin as means of payment, uses reward tokens, and harnesses smart contracts to offer a solar project insurance fund and to integrate a MRV solution. Until June 2021, more than 40 projects had been completed, totaling around 5.2 GWh of clean energy.

At the same time, insurance companies are exploring the potential of DLT to improve their business cases, while startups are developing new insurance products. Potentials of DLT for the insurance sector encompass event-triggered smart contracts, disintermediation, better risk assessment, general efficiency gains, new types of insurance, and the broadening of the customer base. The first aspect is pivotal because smart contracts allow for fast and automated pay-outs in case a specific event happens, which is identified by consulting external data via oracles. Streamlining insurance also means access to insurance for the un(der)insured, which enables them to hedge against livelihood risks. Naturally, insurances play a key role in climate adaptation by cushioning risks related to extreme weather events such as droughts, floods, or storms.

**Etherisc**: Formed in 2016 with the aim to make insurance fair and accessible, the non-profit Etherisc foundation provides a platform to facilitate the building of new DLT-based insurance products. This decentralized insurance platform is based on its generic insurance framework and its decentralized insurance protocol. The protocol leverages the Ethereum sidechain xDain and utilizes smart contracts as well as tokenization. The for-profit Etherisc company serves as a first mover on the platform to create products that generate revenue, which ensures the development of the platform. Its main product is flight delay insurance, but more insurance products are under development. This concerns hurricane protection and crop insurance, which are designed for low-income individuals and small business owners, hedging against hurricanes, droughts, or floods. The payouts of those insurances are triggered by specific events, which are identified by consulting external data via oracles. Such index-based insurances are called parametric insurances.

**Arbol**: In 2018, the company was founded to provide a DLT-based parametric insurance against extreme weather for businesses, putting a focus on fast payouts in case predefined events happen. Arbol’s design eliminates the traditional claim process and provides security of payout for customers. The solution is based on the Ethereum blockchain and uses smart contracts. It leverages Chainlink’s oracle network as well as tokenization of climate data. The company offers products for the agriculture, energy, maritime, and hospitality sectors by offering insurance against rainfall, snow, temperature, humidity, crop yield, wind, and other weather-related risks.
13.3.2 Asset Management

This section deals with the utilization of DLT in financial asset management, which promises to bring increased security and transparency to investors and improve backend efficiency, thereby reducing costs for providers. Applications can take on various forms, as not only private but also public entities explore DLTs. In April 2021, the European Investment Bank (2021) issued its first digital bond on a public blockchain. These initial implementations of DLT in the financial system lay the cornerstone for successful large-scale climate finance applications in the future.

First, we consider DLT with regard to the improvement of existing asset management systems. Integrating DLT and smart contracts into the administration of funds or bonds can automate workflows and tighten related processes, which enhances backend efficiency and regulatory compliance. Efficiency gains have been estimated by HSBC and Sustainable Digital Finance Alliance (2019) to more than 10X. This particularly concerns the issuance of green bonds, for which Malamas et al. (2020) propose a DLT-based architecture.

BBVA—Structured Green Bond: In 2019, the Banco Bilbao Vizcaya Argentaria (BBVA) issued a first DLT-supported structured green bond of 35 million euro tailored to the needs of one of their investors. The bond runs on BBVA’s own blockchain-based platform that utilizes smart contracts, automating the arrangement, negotiation, and issuance processes. This allows the investors to configure their own bond according to their needs, limited by the boundaries set by the issuer. This DLT-based setup reduces costs for the entire lifecycle of green bonds, thus facilitating their establishment.

The reporting process for green assets such as funds or bonds can benefit from the increased transparency and improved auditability of projects. This can be achieved by utilizing DLT as a data transmitting layer. Investors receive tamper-proof information about the sustainability metrics of projects, as well as aggregated metrics of the project portfolio they are invested in. Integrating DLT directly at the impact data generating source and in the entire data trail would constitute a more extensive approach, which is studied in the following subsection.

Green Assets Wallet: Launched in 2017 by Stockholm Green Digital Finance and a consortium of diverse entities, the platform aims to bridge sustainable investors with green investments. Issuers can demonstrate credibility and showcase their project’s impact to attract investors. Thereby, investors are provided with trusted impact data, enabling them to better evaluate potential investments. Similarly, the entire lifecycle of a project is tracked on the platform and impact metrics are shared with investors. The platform utilizes the Chromia relational blockchain technology that combines the concepts of relational databases and blockchains. This integrated approach guarantees immutability of data inputted by projects and investors, thus establishing a standard between market participants.

Funds and bonds become more transparent based on this process, which enables the sector to harmonize reporting standards, and to ease benchmarking. Even though there are more recent regulatory attempts to define sustainable activities (e.g., European Commission 2021b), the transparent implementation in funds and bonds is not straightforward. DLT can be vital to address this issue and improve the comparability of funds and bonds. DLT can also enable new types of asset management because of
its decentralized nature. For instance, the entire asset management lifecycle can be implemented as a dApp, which is managed through the rules enshrined in its setup. This can be transferred to portfolio management, so that a portfolio is managed by a dApp. To fully decentralize portfolio management, a DAO can be formed to take over based on predefined rules for decision-making. Another tangible application is enhanced portfolio diversification, which can be enabled by tokenizing larger investments and cutting them into smaller pieces, thus providing more and smaller investment opportunities (HSBC and Sustainable Digital Finance Alliance 2019). This option expands the potential customer pool to investors with liquidity constraints for whom large investments have not been accessible, thereby simultaneously expanding the capital pool. In addition, more efficient and automated management systems simplify the pooling of small-scale investments into large investments, which facilitates investments of larger investors (HSBC and Sustainable Digital Finance Alliance 2019). These new types of asset management are still in their infancy and have not yet been fully leveraged for climate finance. However, a number of exploratory case studies examine the potential of linking DLT-based systems to green funding sources, for example, in the context of the Green Climate Fund (e.g., Schulz and Feist 2021).

13.3.3 Measurement, Reporting and Verification

Closely connected to climate finance and asset management are processes of MRV, which are used to determine the sustainability impact of a “green” asset. DLT can serve as a trust-creating data layer for MRV processes and enable their automation (Dorfleitner and Braun 2019). Verifiable, transparent, and trustworthy MRV processes are essential for investors, as they wish to invest in credible and impactful green assets. If sustainability is not guaranteed, investors often lack trust in the green asset. Solving the trust issue would enhance the credibility of a financial product and also prevent the greenwashing of assets. This means streamlining MRV processes is pivotal in boosting climate finance from the investor perspective. The streamlining process can be facilitated by using DLT to directly link devices such as sensors in cyber-physical systems to investor(s), so that an automated, traceable, and trustworthy trail of tamper-proof data, from generation to data use, is established. Such data could include the amount of CO2 emitted, or the amount of electricity generated. MRV processes become more transparent and cost effective with such a streamlined approach, for example, by improving the monitoring and tracking of the asset’s performance, including its impact, along the lifecycle. The automatization of data flows also facilitates the digitalization and certification process of green assets.

_Distributed Renewable Energy Certificate (D-REC) Initiative_: Announced in January 2021, the initiative’s objective is to create a global market for distributed renewable energy to connect corporate finance and small-scale renewable energy projects. Through the creation of tokenized D-RECs, which are based on the International REC (I-REC) Standard, a globally recognized proof of electricity source is established. One certificate corresponds to 1 MWh of generated electricity, which is stacked by the production of several small-scale
facilities. The certification process is handled by approved I-REC issuing bodies, taking into account generation data automatically provided by electricity meters. In the future, this semi-automated process should be fully automated based on oracles importing the generated data and the automatization of certificate issuance.

**Digital MRV™**: Initiated by the IOTA Foundation and ClimateCheck in 2020, the pilot project streamlines MRV processes by utilizing data produced by various IoT sensors on-site to create digital twins of facilities on a DLT. The used IOTA protocol is directly integrated on gateway devices, which reduces MRV costs and creates trust in the generated data directly at its source. This streamlined process produces a near real-time representation of the facility’s activities that facilitates the creation and verification of tokenized carbon credits, which will be added to the project in the future. This holistic approach from data generation via impact information to carbon credit certification, links credible impact information with carbon credits and can incentivize sustainable economic growth via carbon trading.

**Evercity platform**: Founded in 2018, Evercity works on two projects to increase climate finance. First, it develops a smart sustainable bond protocol based on the Polkadot protocol that facilitates the issuance and management of green bonds. Second, it develops a blockchain-based platform that simplifies the matching of professional sustainable investors and impactful projects by improving asset issuance, impact measurement, project monitoring, and reporting. Features include the integration of data generated by IoT devices, drones, and satellites for impact measurement, as well as the issuance of carbon credits.

The process of carbon credit certification is currently a costly process, especially in developing countries. Reduced costs incentivize projects to qualify their carbon reductions as actual carbon credits. Such tokenized carbon credits could be traded on a global market and create new revenue streams for green projects, thus improving unit economics, which in turn incentivizes the establishment of additional projects. However, innovative certification processes also require improved MRV processes based on reliable, tamper-proof data trails and credible source data that can be established by using DLT and tokenization.

### 13.3.4 Tokenization

In addition to the native token of a DLT protocol, some protocols also allow for the creation of additional assets. The underlying idea is to make assets more accessible and simplify asset transactions. As described in subsection 13.2.1, the object of representation can be any kind of real or digital asset. Tokenized assets can serve a variety of purposes: from governance tokens of DAOs or utility tokens and NFTs to tokens representing the value of a real-world asset (security tokens). The main risk of some kinds of tokenization is issuer risk, which directly relates to the credibility of a claim. If an issuer promises, for instance, a future interest payment to the token holder, the token value depends on the credibility of the said claim. The back-up of such promise-based tokens can take the form of either off-chain or on-chain collateral, or no collateral at all (Schär 2021). In the following, relevant application areas of tokenization in the context of climate finance are studied, even though other climate-related approaches like reward tokens are promising as well.
In the previous subsection, we already introduced the key links between MRV and carbon credit certification. Article 6 of the Paris Climate Agreement, in particular, establishes the use of Internationally Transferred Mitigation Outcomes (ITMOs) between countries for achieving national contributions, which constitutes the cornerstone for a global carbon market that allows green capital to flow where it can be used most efficiently for mitigation. Nevertheless, Article 6 has not been operationalized so far, although important progress on its implementation has been made at the UNFCCC COP26 summit in Glasgow. Automatization, transparency, and enhancements of carbon credit certification through DLT could be used to ascertain the underlying quality of carbon credits, which could then pave the way for a functioning global carbon market. Franke et al. (2020) and Kim and Huh (2020) elaborate such a DLT-based system.

**BITMO platform:** In 2021 at the COP26, the Blockchain for Climate Foundation launched the Blockchain Internationally Transferred Mitigation Outcomes (BITMO) platform that enables national governments to issue and exchange carbon credits. The platform uses the Ethereum blockchain and represents carbon credits as NFTs. The project aims to become the infrastructure to operationalize Article 6 and enable carbon trading on a global scale.

Similarly, Mandaroux et al. (2021) propose the use of DLT to digitalize the Emissions Trading System for the EU. Other approaches for establishing carbon markets specifically target companies and individuals wishing to offset their carbon emissions.

**ClimateTrade:** Founded in 2017, the company supports companies to achieve carbon neutrality by offsetting carbon emissions via its marketplace. The marketplace is geared toward the needs of companies that want to offset and simplifies the offsetting process. Projects that are used to offset emissions only enter the marketplace after a manual assessment by the team of ClimateTrade, ensuring high-quality projects, which can be manually selected by companies that want to offset. The marketplace utilizes Algorand’s Pure Proof of Stake blockchain technology that allows for a high throughput and sustains traceability and transparency of carbon credits. So far, the company has offset more than 1 million tons of carbon.

**ECO2 Ledger:** In 2018, the ECO2 foundation started to work on the ECO2 Ledger, a blockchain-based carbon market network that enables carbon trading between individuals. Carbon neutrality of the Nominated Proof-of-Stake blockchain network is sustained by using transaction fees to buy and consume carbon credits. The ledger serves as backbone for sustainability dApps that can be built on top. MyCarbon, the first finalized dApp, provides a tool for personal carbon accounting and enables individuals to directly trade carbon credits.

All the aforementioned types of carbon markets can accelerate capital flows to projects with the highest efficiency in reducing carbon emissions. Another important feature are new revenue potentials for project issuers. Both benefits can speed up the development of new projects. However, the main issue for the establishment of functioning global carbon markets is non-standardized carbon accounting, which resulted in different certification processes and siloed exchanges. The InterWork Alliance (2020), an association of private sector and DLT organizations, addresses this issue and is working on defining global standards for tokenization of emissions, offsets, and trade contracts.
Tokenization is linked with asset management because of the opportunity it creates to pool and chop investment, together with the ability to create new digital representations for various tangible and intangible assets. The former is especially important for issuers of funds and bonds. Schletz et al. (2020) explore the potentials of the latter by researching tokenized securities that are digital representations of security assets, which can be debts, equity, or asset-based tokens. Contrary to other kinds of tokenization, security tokens must comply with legal regulations by nature. The authors conclude that the potential for green finance is promising but applications are limited by immature technological infrastructure and regulatory uncertainty. Nonetheless, combinations of tokenization with novel financial product schemes show promise.

ixo protocol: The ixo Foundation, formed in 2017, develops the blockchain ixo protocol that enables everyone to deliver, evaluate, or invest in sustainable development impacts by utilizing non-fungible impact tokens that represent proof of impact. Impact certification of verifiable impact claims is done by independent, certified verification agents who are supported by high-definition data and prediction oracles. Impact tokens serve as community currency in the Internet of Impact and can be configured into outcome-based financing mechanisms. To power novel sustainable DeFi services AlphaBonds, which automate market-making and dynamically adjust parameters in response to real-world signals, are built and utilized in first pilot projects.

Another area of application are utility tokens. Examples include a variety of energy projects like Greeneum, Power Ledger, Rowan Energy, or WePower that use tokenization on their platforms to represent green energy and enable P2P energy trading. Some also integrate financing mechanisms, such as the investment of tokens in energy projects.

13.3.5 Other

In addition to the previously discussed applications, DLT can also be deployed to improve social funding schemes such as crowdfunding platforms or community-based approaches, which are not merely driven by monetary incentives, for example, in sustainable and social entrepreneurship (Dorfleitner et al. 2021). Community-based DLT approaches in combination with climate finance hold the potential to benefit local communities and to improve localized climate finance. Yoshino et al. (2020) propose a DLT-enhanced version of community-based hometown investment trust (HIT) funds, which provide financing for local small-scale renewable energy projects and have already been used in multiple countries. The underlying idea of HIT funds is to create a trustful, spatially close opportunity for individuals to invest small amounts in local projects. DLT can add trust in the proper functioning of the funds through its security, transparency, and auditability characteristics. Accordingly, the potential investor pool could be expanded across borders, so that projects in developing countries are able to access climate funding from abroad.
One key problem in climate finance is a general lack of investment opportunities because of a lack of credible projects. Project leaders often spend a lot of time searching for funding opportunities when they could improve or develop projects instead. In addition, new projects often lack the quality to attract direct funding. This means improving projects could broaden the supply side. DLT can facilitate network platforms by creating trust between parties and streamlining certain processes.

**Interactio**: Initiated in 2019 by the World Wildlife Fund (WWF), the platform aims to get projects off the ground by identifying impactful projects, providing them with external advice, and enabling the most promising ones through matchmaking with implementation and funding partners. The platform’s main objective is to enable “global collaboration to curate, support, and deliver high-quality impactful solutions” to achieve the SDGs. Interactio utilizes the Ethereum blockchain as well as its smart contract and tokenization features. Tokens on the platform have no monetary value and serve as behavioral motivators to assist the processes of curation and selection of projects as well as matchmaking. External subject matter experts (or curators) play a pivotal role on the platform because they review projects, provide feedback, and decide on the quality and impactfulness of projects.

Approaches to reward good behavior can contribute to climate finance if created incentives cause behavioral changes. For instance, SolarCoin established its own cryptocurrency that rewards solar electricity producers who can claim one SolarCoin per MWh they produce. Even though monetary incentives created by the value of SolarCoins are insignificant, the non-monetary gratification reward could motivate producers to establish new projects.

### 13.4 Conclusion and Policy Implications

The underlying technologies of distributed ledgers have significantly evolved. Solutions for most technological limitations are on the horizon and point toward the broader adoption of DLTs in climate finance. Yet, it is crucial that DLTs become more sustainable to avoid situations in which emission reductions through DLT applications are offset by the overall resource consumption of the digital system. In addition, it is paramount to establish an enabling regulatory environment to fully leverage the potential of DLTs. This entails reconciliation with legal concerns over privacy, value transactions, accountability, liability, and anti-money laundering, as well as global standards to create secure and interoperable solutions and markets.

From a climate governance perspective, DLT promises significant efficiency gains together with increased interactional transparency, which, in turn, could lead to more successful cooperation and higher levels of trust. One specific DLT solution that holds great promise for advancing high-impact climate finance is the design of an end-to-end process for issuing green bonds that simultaneously ties in with open and nested climate accounting. In a multilateral climate governance setting, this would necessitate collective action toward the integration and scaling of existing but fragmented DLT climate, sustainability, and FinTech applications in alignment with the Global Stocktake process under the Paris Agreement. Promising regulatory initiatives like
the MiCA and DLTR regulations (European Commission 2020), the EU taxonomy (European Commission 2021c), or the European green bond standard (European Commission 2021b) are designed to tackle these issues. As regulatory frameworks, they pave the way for the broad adoption of DLT-based financial products, so that, for instance, security tokenized green bonds can become regulated financial instruments. Equally important is the standardization of green financial products, project impact measurement as well as the tokenization of emissions and carbon offsets. Here, a decisive role falls to DLT-based MRV processes, which guarantee the credibility of source data and create reliable and tamper-proof data trails. The integration of DLT oracles with IoT devices is also desirable for data correctness because such a setup would increase trust for all parties and facilitate compliance with regulations and standards.

Adequate resources are also needed to link global policy frameworks and carbon markets to local and community-driven DLT solutions, for example, through a proof of concept for an end-to-end digital green bond. Such an integrated approach based on nested and open climate accounting could contribute to the removal of financial frictions and barriers with the aim to democratize securitized impact investing for community projects. These investments could then be used as a vehicle for sustainable local economic development. Developing countries, in particular, could drive this innovation by introducing enabling national legislation to foster the use of DLT-based solutions and supplement existing financial mechanisms. In combination with enhanced MRV processes, such a favorable regulatory environment could create access to climate finance and generate new sources of revenue for sustainable projects. However, a vibrant national and international DLT sector requires regulation and extensive technological knowledge on all fronts. Trusted cooperation within initiatives and networks will be crucial to advance, exchange, and disseminate relevant knowledge, as we have illustrated in our analysis. Equally important are direct public investments in education, so that the created regulatory security can be utilized in the first place, and existing digital divides between developed and developing countries can ultimately be narrowed.

Appendix

See Table 13.2.
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