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SEI Stockholm Environment Institute

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Infrastructure for Article 6 MRV and transfers – the potential of blockchain-based technologies

Final Report

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In cooperation with

cosmos

CLIMATE LEDGER INITIATIVE

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Disclaimer: The views expressed in this report are the authors' own and do not represent any official position of the commissioning agency.

This report is dedicated to Sven Braden, who unexpectedly died of Covid-21 at the beginning of this mandate in June 2021. Environmental Lawyer, seasoned market mechanism negotiator and energetic Program Manager of the Climate Ledger Initiative, we will remember Sven as a key driver for environmentally sound and sustainable market mechanisms and a fervent but sober promoter of the use of blockchain for climate action, who never got the human factor out of sight. He was a dear friend. We miss him.

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Content

Executive summary

In contrast to earlier carbon market mechanisms under the Kyoto Protocol, the Paris Agreement's Article 6 mechanisms move away from centralized accounting, unified comprehensive rules and standardization for the monitoring, issuing and transferring of international units by allowing loosely defined decentralized cooperative approaches. This more bottom-up approach requires Parties to 'ensure environmental integrity and transparency' and to 'apply robust accounting to ensure, inter alia, the avoidance of double counting'.

Any cooperative approach under Article 6 requires the establishment of robust institutional settings, regulatory frameworks and reliable and trusted information systems in the form of a registry. Such a registry system has to track mitigation outcomes along the process cycle of ITMO transfers, including authorization, measuring, reporting and verification (MRV), issuance, transfer, corresponding adjustment, cancellation, etc.

The use of a decentralized blockchain, or more generally distributed ledger technology (DLT), and other digital innovations for electronic registry systems and MRV may provide numerous benefits compared to the use of a conventional centralized database. They include increased security, as blockchain/DLT entries are immutable and therefore provide for additional trust, which may be particularly important in the context of countries with weaker institutional capacities and governance settings. Also, the digital technologies provide for additional levels of automatization (e.g. in "smart contracts") increasing not only trust in the functioning of the system but lead also to efficiency gains in the project transaction cycle. Blockchain/DLT systems may also be better suited to connect different registry systems and thus allow for the linking of a multitude of heterogenous carbon markets.

However, depending on the technology used, blockchain technologies/ DLT may also have limitations compared to conventional databases, including lower transaction speed and capacity, and high power consumption and transaction costs (depending on the consensus mechanism[1]). Approaches to overcome these shortcomings include, for instance, hybrid approaches, combining conventional databases with an immutable blockchain/DLT layer.

Please note that the present study has been elaborated before the adoption of the Article 6 rulebook at COP 26 in Glasgow in November 2021 and therefore it does not provide specific guidance on the newly defined *international registry*, the *Article 6 database* and the *centralized accounting and reporting platform* as well as the (Article 6.4) *mechanism registry*. Our findings also hold in the context of the newly defined Article 6 registry infrastructure.

[1] In simple words, the «consensus mechanism» is the process with which the system decides which node is allowed to add the next data-block to the blockchain. In the Proof of Work approach, node that first solves a cryptographic puzzle using a lot of processing power and energy is allowed to add the next block to the chain.

The following findings and preliminary conclusions are based on an initial analysis of the requirements of future Article 6 registries, the experience from the coding of a simple registry system by IT partner Cosmos, and a technical workshop with the SEA and project team:

- If SEA wants to implement the registry system focusing purely on its domestic needs, then a conventional database may be a better solution. Such a system may be locally efficient and, in a domestic system for Sweden, public trust in government and public databases is high enough that there is no need for a technological trust layer trough blockchain/DLT.
- On the other hand, cooperation between countries is efficient in climate action and helps building an Article 6 community of partners. Sweden, as an internationally well respected and neutral country, may together with similar minded countries form the nucleus of an international Article 6 registry and transaction infrastructure that can attract many other countries to join based on its usefulness, trusted technology and high environmental integrity.
- As Sweden is already well advanced with the piloting of Article 6 activities and wants to start implementing activities and transacting mitigation outcomes, a "wait and see" strategy is not to be an option for SEA.

From a technical point of view, the following preliminary recommendations are made based on the analysis:

- In order to start developing concepts for a joint approach to developing Article 6 registry infrastructure, it is important for SEA to learn more about the specific needs and expectations of host and acquiring countries, and other partners, including in terms of technological functionality, standards, as well as governance and readiness to share sovereignty with partners.
- If SEA seeks to work in cooperation, then blockchain/ DLT has numerous benefits and can be implemented such that potential limitations (e.g., capacity, power consumption, transaction cost) can be largely overcome.
- The blockchain/DLT would be owned and operated by a consortium of partners which may include other host and acquiring countries, standards, MDBs etc.
- From the limited analysis of this study, a private permissioned blockchain/DLT operated by a defined consortium may be the optimal solution for backing a registry system. This solves issues with governmental oversight and can be better aligned with existing national and international regulations. In addition, it does not require energy intensive consensus mechanisms and does not need to rely on a major third party blockchain/DLT operator.
- In order to be able to handle the required number of transactions and provide enough data storage e.g. to document additional attributes of ITMOs (including e.g. sustainability benefits), a hybrid system may be an optimal solution. This would combine

- a conventional database containing the main data of the registry including on mitigation activities and units,
- a blockchain/DLT system containing a hash (i.e. a "digital fingerprint") of the overarching database, that can be used to assure the trustworthiness of the data.

Other approaches may include advanced concepts of second layer blockchain/ DLT systems, which seem not yet sufficiently developed.

- A specific approach to a hybrid solution would be that the consortium owns and manages an underlying synchronization layer blockchain/ DLT (see Figure 2). This common synchronization layer serves as a secure, immutable log of all registry activities in the participating registries of the consortium members.

Once the technical and institutional specifications are further developed it is advisable to clarify the specific blockchain/ DLT type that is most suitable for the required registry system. Also, at that stage, the pros and cons of blockchain/DLT based systems should be carefully reassessed against conventional database solution where trust is less based on (blockchain/ DLT) technology but on the institutional level (e.g. similar to the existing UNFCCC CDM registry).

In any case, while it appears that there is sufficient interest from different parties and organizations in a joint and coordinated approach to an Article 6 registry and transaction system, it is important to start early with discussions with potential partners in order to reach an agreement on jointly developing a robust pilot system.

1. Introduction

The adoption of the Paris Agreement (PA) forms a new area for international carbon market mechanisms and the infrastructure requirements for monitoring, reporting and verification (MRV) and international transactions under its Article 6. The fact, that all countries under the PA have national commitments (Nationally Determined Contributions, NDC) to reduce greenhouse gas emissions, reinforces the importance of robust MRV systems to capture the mitigation outcome[2].

In contrast to earlier carbon market mechanisms under the Kyoto Protocol, the Paris Agreement's Article 6 mechanisms move away from centralized accounting, unified comprehensive rules and standardization for the monitoring, issuing and transferring of international units by allowing loosely defined decentralized cooperative approaches. This more bottom-up approach requires Parties to 'ensure environmental integrity and transparency' and to 'apply robust accounting to ensure, inter alia, the avoidance of double counting'. The international climate negotiations under the UNFCCC have so far (as of July 2021) not been able to agree on how these principles are to be translated into practice in the so called "rule book").

The resulting heterogeneity in emission accounting systems for Article 6 mechanisms magnifies the challenges associated with assessing, tracking, and comparing actions of different countries. Robust infrastructure for MRV, for transferring mitigation outcomes and tracking their use towards own reduction targets are key. The supporting infrastructure must be able to map this heterogenous practice and allow for maximum flexibility, while ensuring transparency and adherence to the rules established through the top-down elements. Digital solutions such as blockchain[3] and related technologies can help reaching the required transparency and efficiency goals.

Digital solutions can improve data collection procedures and digitize the MRV process of mitigation actions. In addition, digital solutions such as blockchains could form reliable and secure registry platforms. Furthermore, blockchain can serve as an aggregation platform, a 'ledger of ledgers' or meta-registry, linking all heterogeneous emission systems in one platform (e.g. The 'ClimateWarehouse' proposed by the World Bank for linking national registries) (Schletz et al. 2020).

Even before the adoption of the Article 6 rulebook at COP 26 in Glasgow, practical Article 6 piloting has started in some countries. The Swedish Energy Agency (SEA) has been engaged with piloting Article 6 activities by exploring ways to support the development of mitigation

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[2] Please note that the present study has been elaborated before the adoption of the Article 6 rulebook at COP 26 in Glasgow in November 2021 and therefore it does not provide specific guidance on the newly defined *international registry*, the *Article 6 database* and the *centralized accounting and reporting platform* as well as the (Article 6.4) *mechanism registry*. However, our findings also hold in the context of the newly defined Article 6 registry infrastructure.

[3] In this report we use the term «blockchain» as a simple placeholder for a whole range of distributed ledger technologies (DLT), as in CLI 2018a.

activities that could potentially generate mitigation outcomes. The work of SEA so far focused more on a conceptual level and has not yet concluded in Article 6 transactions. As a part of its piloting activities, SEA commissioned “virtual pilot projects” to be developed in several host countries with the aim to better understand the key aspects (technical, financial and legal) that would need to be addressed for an Article 6 pilot to be implemented[4]. SEA now aims for piloting Article 6 activities in a very concrete way and starts implementing projects in host countries while the details of the Article 6 “rule book” are still to be agreed on internationally.

In parallel to the piloting of Article 6 activities, SEA is considering how to digitize the necessary registry infrastructure and related processes (authorization, MRV, issuance, transactions, corresponding adjustments).

The aim of this study is to provide insights on the potential of blockchain and related digital innovations for the SEA’s digital Article 6 infrastructure and informs SEA on the pros and cons of different approaches. Furthermore, the study shall increase the understanding in the field of digital infrastructure for Article 6 implementation, regarding registry, MRV opportunities and linking with international structures.

In parallel to this study, a demo/ prototype of working elements of an Article 6 registry are developed in order to gain practical experiences to complement the findings of this paper.

2. Article 6 registries and digital MRV

The following section will introduce the main actors and processes involved in a proposed Article 6 registry system, focusing on the simplest possible form and then extending the scope and describing additional elements. The analysis builds on own analysis and earlier work by the authors.

2.1 A registry infrastructure for Article 6 transactions

Any cooperative approach under Article 6 requires the establishment of robust institutional settings, regulatory frameworks and reliable and trusted information systems in the form of a registry. Adapting findings from Barata et al. (2021, Section 10.3), Dinguirard et al. (2016), and Spalding-Fecher et al. (2021), registry systems serve the following purposes:

- To promote **transparency** by providing publicly accessible information on mitigation interventions (projects, programmes etc.). This may also include attributes e.g. on project type, methodology and standard used etc that may inform users on the quality of specific mitigation outcomes;

[4] http://www.energimyndigheten.se/en/cooperation/swedens-program-for-international-climate-initiatives/cooperationunder-the-parisagreement/challenges-and-opportunities-for-operationalizing-article-6/

- to facilitate the **issuance, transfer, and use** of uniquely identifiable mitigation outcomes[5] that are clearly linked to, and convey a claim to the outcomes achieved by, registered mitigation activities; and
- to help **prevent double use and double issuance** of emissions reductions and removals. Linking to other registries can also reduce the risk of double issuance and use.

To that aim, registries may consist of (at least) two main components, that may be maintained and administered separately or in one system:

- a sub-registry for the tracking of **mitigation outcomes**, documenting their issuance, transfer, use and/ or cancellation;
- a sub-registry for **mitigation activities** for the (public) documentation of key characteristics of the mitigation activities underlying the related mitigation outcomes. This includes all documentation of the project cycle, e.g. approvals, third-party validation and verification documentation, etc. and may also include attributes related to sustainability benefits of the activity beyond the carbon component.

Registries need to be embedded into a related international and national institutional and regulatory framework (PMR 2016). For instance, the legal framework regulates issues in data protection, confidentiality and disclosure, the legal nature of the carbon "units" and their tax status. Also, it requires rules to define the legal status of electronic "ledgers" or "tokens". The framework needs also to clarify the responsibilities for the management, operation and supporting processes.

2.2 Essential actors in an Article 6 transaction

Different actors are involved in an Article 6 transaction. In the following, we provide a description of key actors:

Host country authority. Host countries need to establish institutional arrangements and processes for authorizing international transactions under Article 6. In particular, the host country authority has the authority to authorize and transfer mitigation outcomes under Article 6. Host countries may undertake a mitigation planning exercise, in order not to oversell mitigation outcomes and therefore risk to not achieving their NDC (Schneider et al. 2017, [insert SEA paper overselling]). Depending on the outcome of their analysis, host countries may limit authorization to certain project types, geographies, technologies, and may limit the maximum amount or share of mitigation outcomes that may be internationally transferred from a given mitigation activity. Additional criteria for authorization that the host

[5] We use the term "mitigation outcomes" somewhat loosely for what may also be called a "unit" or "certificate" that represents *a claim* in the registry to an actual mitigation outcome.

country may apply include policy alignment, SDG and host country development contribution etc.

Article 6 **activity proponent**. While Article 6 describes the cooperative approaches between countries, it may be assumed that in reality many actors actually implementing mitigation actions are from the private sector. Project proponents arrange for registration of mitigation activities, submit document supporting the host country authority's decision to authorize transfers, arrange for the activity's documentation and MRV. After submission, they need a legal entitlement to claim the mitigation outcome on the registry. This legal right is then their basis to go into purchase agreements and sell the outcomes on to other private or public entities. Then an adequate contracting arrangement needs to be established between the host country government and the private sector activity proponent. The activity proponent's role may be partially or fully covered by public entities. For instance, in sector or policy crediting, the rights in mitigation outcomes on the registry may stay with the host country government and private sector players may (or may not) be compensated financially for their mitigation efforts. The adequate inclusion of private sector actors appears to be a crucial element of making an Article 6 registry infrastructure work.

Acquiring country authority. International transfers of mitigation outcomes also have to be authorized by a suitable acquiring country authority (e.g. within the Swedish government). Acquiring countries may have their own set of regulations, rules and quality standards that define, which types of mitigation activities and related outcomes are eligible for transfer into the country for meeting the NDC. For example, Switzerland defines in its CO2 law criteria for mitigation outcomes that are eligible for compliance with its specific goal to be covered by international crediting.

Validation and verification bodies (VVB). These are independent third-party entities that carry out validation of proposed projects and related methodologies and, once the activity has started and mitigation outcomes are generated and monitored, VVBs verify the data of the monitoring reports against the requirements of the project documents and the methodology and certify their validity. Only once the verification report is submitted, the related mitigation outcomes can be issued into the related account of the registry system.

Additional actors may be considered accessing an article 6 registry infrastructure. Once an acquiring country has authorized the transfer of mitigation outcomes into the country's registry accounts, they may be transferred to any (public or private sector) off-taker. Such off-takers may also be active on the host country side. The following cases may be considered:

- Off-taker uses mitigation outcomes in a compliance market (e.g. for an installations under a domestic emission trading scheme to comply with emission caps, or for airlines to comply with the requirements of ICAO)
- Off-taker uses mitigation outcomes in a voluntary market (e.g. a company offsetting its corporate scope 1 emissions through purchasing and cancelling/ retiring mitigation outcomes on the registry)

- Off-takers that act as intermediaries and traders, using the mitigation outcomes as an investment, benefitting from arbitrage or providing derivative products for the market (e.g. futures, options, etc.)

All these different actors will need different kinds of access to the registry. An overarching regulation and governance setting will need to define the detailed rules of the registry, including their specific access rights, transparency and anti-fraud provisions as well as the data protection regulations.

2.3 Essential processes of an Article 6 transaction

While the requirements related to accounting and reporting of countries' GHG emissions and emission reductions under the newly established enhanced transparency framework under Article 13 appear reasonably clear, there still remains a lot of uncertainty about accounting of transfers of mitigation outcomes that are expected to happen under Article 6 mechanisms. For this paper, we pick out some of the most relevant processes for an international transfer under Article 6. This serves as a sketch for processes to be demonstrated in the demo/ prototype blockchain system that is developed in parallel to this study.

Table 1. Simplified steps for process related to ITMO transfer under Article 6

Process step	Main actor	Description	Data example
Authorization	Natl. authority (host)	Project approval and authorization of ITMO transfer. The host country may want to limit the maximum amount of ITMOs to be transferred by a specific A6-intervention ex-ante in order to prevent overselling risk	yes/no Project no. Max. no of ITMOs
MRV	A6 Project proponent	Regular (e.g. annual) monitoring, reporting and verification of performance data of A6-intervention Translation of performance into net GHG reduction	10 GWh of wind power 5000 tCO_2
Issuance	Natl. authority (host)	Issuance of reduced GHG emissions[6] into national registry of host country	5000 tCO_2
Transfer	Natl. authority (host)	Transfer of mitigation outcomes from host country to acquiring country account	5000 tCO_2 Other attributes[7]

[6] respectively to "credits" relating to said emission reductions or mitigation outcomes.

[7] Other attributes that are transferred together with the ITMO may include serial number, project name, project type, exact location, year of reduction, methodology used, SD-benefits, etc.

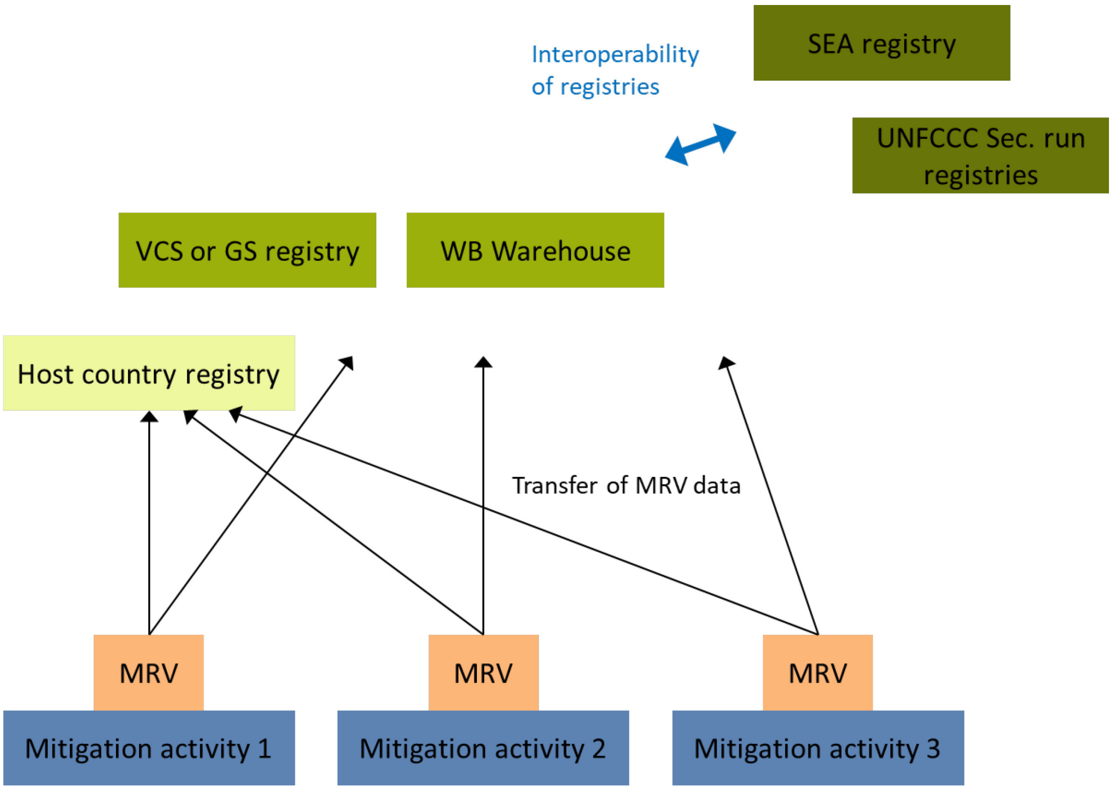
Process step	Main actor	Description	Data example
Corresponding adjustment	Natl. authority (host)	When reporting adjusted emissions in a structured summary for purposes of NDC compliance, the host country adds back the amount of transferred mitigation outcomes to its GHG inventory (outside of registry)	5000 tCO2
Cancellation	Any holder of ITMOs	Transfer of ITMOs to cancellation account, so that they cannot be used anymore	5000 tCO2 Other attributes
Use towards NDC and annual information	Natl. authority (acquiring)	This is part of the (expected) *annual information* on ITMO authorization, transfer, acquisition, holdings, cancellation, use towards NDCs,	5000 tCO2 Other attributes[7]

Source: Own analysis. Note that the detailed requirements for international transfers under Article 6 are uncertain at this point in time (October 2021).

Additional elements that may be considered in the context of the registry infrastructure may include the following:

Last mile issue. The secure transfer of data from the sensor or flow/ power meter as part of a MRV system to the related monitoring database and finally the registry system is challenging. Different approaches have been considered (see section 3.2 in CLI 2019).

Integrating a multitude of registries. over the next years, the parallel development and operation of a multitude of electronic registries (including from host and acquiring countries, voluntary standards (Verra, Gold Standard, CAR, …) may be expected. The registries will be fed directly by primary data from MRV systems related to different mitigation activities, however, many will mirror and duplicate the content of underlying or parallel registry systems. This creates specific challenges of interoperability and synchronicity that are discussed in Section 4.1). A particular variant of this are meta-registries that serve as an aggregator of information on a large number of registries, such as the World Bank climate warehouse concept.



Source: Adapted from Fuessler and Herren (2015).

Figure 1 – Overview: Climate action, MRV and related registry systems.

3. Overview on blockchain technologies for MRV and Article 6

In the following, we provide an overview on key opportunities and issues when using blockchain or Distributed Ledger Technologies (DLT[8]) and related digital innovations, first for MRV more specifically, then for Article 6 registry systems. The chapter ends with some recommendations.

3.1 Digitized MRV systems as part of A6 infrastructure

Challenges with conventional MRV

The Measuring, Reporting and Verification of greenhouse gas (GHG) emission reductions (MRV) is a key element of climate change impact measurement. The importance of MRV is to collect and evaluate evidence to provide reliable information that enables more efficient and effective climate action. There is over 25 years of MRV practice and yet there remain major

[8] The more common term «blockchain» is sometimes used as a simplifying placeholder for the much broader concept that includes all distributed ledger technologies («DLT»), even though blockchain is only one implementation of DLT. In order keep the report accessible for different readers, we usually state both terms.

challenges, including but not limited to low efficiency, credibility, utility and cohesiveness of MRV processes and results (Baumann 2020).

Conventional MRV tends often to be **costly** and **difficult to implement**, particularly where the collection of spatially diffuse or hand-collected information is involved (e.g. for numerous individual efficient cook stoves), as this drives up the cost of data collection and audit. Another major cost category is the regular verification of data, which is typically done by a qualified and competent third-party entity who conducts onsite visits. As a result, rather than investing in activities that improve the project or policy measure themselves, MRV often end up spending significant amounts on activities that do not directly reduce emissions (GIZ 2019)

MRV processes are also **time consuming**, often meaning that results-based finance or offset units are delivered several months after the fact. Such delays in revenue streams serve as a barrier to many projects. In addition, access to primary data from the project site can be cumbersome. Projects are often located in difficult-to-reach areas where historic data e.g. for baseline setting may be scarce or non-existent. Still today, calculation and reporting of data are usually done manually using complex spreadsheets or by submitting pdfs. This leads to inefficient and lengthy processes that are prone to errors because of the reliance on manual processing of data.

Gaps in data may occur where data is lost or inaccurate or where environmental or political issues prevent site access. Poor site conditions and accessibility, as well as the lack of access to competent staff, can lead to data inaccuracy, bias and **transparency issues**, and affect the reliability and timely delivery of the in-formation. Finally, **human error** is common for projects conducting MRV (GIZ 2019).

New approaches to digitizing MRV

A suite of digital innovations including blockchain/ DLT, Internet of Things (IoT), sensor, remote sensing and artificial intelligence can help overcome existing barriers and enhance the role of MRV.

Box: New approaches to MRV

Internet of Things (IoT): The interconnection via the internet of computing devices embedded in everyday objects, enabling them to send and receive data.

Sensors: Sensors automatically collect and upload usage data for emissions reduction calculations, e.g. Digital Stove Usage Monitors (SUMs) using temperature-logging sensors.

Remote sensing: Process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance (typically from satellite or aircraft).

Artificial Intelligence (AI): is intelligence demonstrated by machines. It describes machines that mimic "cognitive" functions that humans associate with the human mind, such as "learning" and "problem solving.

In general, these approaches can streamline data collection and reporting, increase accuracy, and enable better informed, quicker verification. This can then lower costs, shorten time to market, enable interoperability between carbon markets for greater market access and ultimately deliver higher returns on investment for climate action. It can also engender greater trust in results, through transparency and security and reducing the potential for error (intentional or malicious) through automation (CLI 2018a). A first step in digitizing MRV may include to develop an overview of MRV requirements along the mitigation activity cycle and then to systematically identify those elements that lend themselves best to digitization using above approaches.

The application of digitalization in MRV can offer added value compared to conventional methods and processes in four main areas (CLI 2018a):

Data collection: Technology can dramatically reduce the time and cost of data collection while also improving its accuracy through enhancements like using sensors, smart flux and power meters, or mobile phones to capture data and IoT hubs to automate data processing, thereby removing the potential for human error and increasing reliability. Data needs to be captured safely, securely and properly. Blockchain technology/ DLT, through hashing of data entries, can provide this role and render captured data immutable. This could take place directly at the sensor/IoT level, where data tracking is more immediate, but storage capacity may be an issue, or at a more aggregated level of MRV data.

Impact quantification and reporting: Typically, an emission reduction is calculated from a number of data parameters including usage rates, efficiency ratios, “leakage”, and others. Today, this calculation is usually done manually using complex spreadsheets. Technology could enhance the impact quantification and reporting process through integrated blockchain/DLT-based smart contracts and cloud-based applications linked to IoT-derived data.

Verification: Verification typically involves the review of all data collected for integrity and accuracy as well as conformity to a given methodology. Blockchain technology/DLT can enable real-time third-party verification, whereby data uploaded is continuously checked and verified in real, or near-real time. Automatic verification may include comparing data within time series or with results obtained from other, similar activities to continuously check the plausibility of data and to detect potential irregularities. In some instances, Artificial Intelligence may be used to detect irregularities in data patterns requiring further investigation.

Issuance: Monitored impact data can be translated into issuance of credits to a registry. While not essential for this purpose, tokenization using blockchain/ DLT can create tradeable tokens for monetization purposes through, for example, micro-transactions or crowdsourcing using blockchain technology/ DLT. Tokenization can also streamline the MRV process by seamlessly connecting the impact buyer with those initiating the impact on the ground, bypassing intermediaries.

Appraisal of approaches and recommendation

A wide range of potential technologies can dramatically enhance MRV, including IoT, artificial intelligence, mobile and web applications and Distributed Ledger Technology in two ways: They can increase trust and credibility through robust, accurate and consistent data sources, collection, reporting and verification approaches. Secondly, they increase efficiency by reducing time, complexity and costs through automated data collection or sourcing that can be verified in or near real time as possible.

While it remains clear that the opportunities and benefits afforded by digital approaches in driving trust and efficiency are significant and substantial, there are also challenges and barriers to overcome (CLI 2019):

Upfront finance and capacity are the main barriers to scale. While individual project proponents and technology providers come forward with single or limited application opportunities, for many it remains too expensive in particular with regards to up-front investments in the novel technologies. As is often the case with early phase technologies, additional funding is required to assist with the acceleration, implementation and testing of digital approaches. Therefore, digital approaches may initially impose **higher transaction costs for proponents**, particularly for first adopters and in early phases (providing funding opportunities for donor countries). Conversely, others may be unable to access new approaches due to limited capacity or access to technologies related to their specific contexts. Funding is required to not only support use cases but also to grow capacity and understanding in the sector. Conversely, operation and maintenance of the digitized systems should bring cost savings compared to conventional MRV procedures that are less automated and require more manual resources.

A lack of standardization of approaches makes it challenging for technology developers to establish protocols that can align with climate policy and standards. It may be that for certain technologies it is not yet cheaper to apply a digital approach and will not be until sufficient usage is in place to benefit from economies of scale, which in turn is limited by standards adoption. Standards ensuring interoperability of systems are required on the levels of technology, data and format, human interaction and institutions (see section 4.1).

Governance issues: Digital approaches, particularly those that automatically capture data, may also require enhanced safety, privacy, security and fraud protocols that are beyond the reach of individual proponents to provide (on the governance issue see also CLI and INATBA 2021).

Scaling solutions rely on critical mass adoption to reduce cost of technology, which in turn requires adoption by key organisations and standards. It is challenging for standards operators to provide the flexibility and efficiency of decision making needed to support the introduction of new approaches whilst also maintaining access for those that may not be ready to adopt them. Standards should develop flexible decision making and adaptation approaches to allow for innovation without prescribing or limiting to individual MRV technology solutions.

Monitoring sustainable development matters could be challenging such as evaluating potential project impact on the local environment or the well-being of local communities. Nevertheless, digital identities and digital recordings or other digital data from such consultations may help in documenting and making consultations more transparent. Similar challenges arise for the monitoring of **co-benefits** such as jobs created directly by a project, health impacts or biodiversity benefits (CLI 2019).

3.2 Blockchain/ DLT for Article 6 registry systems

Conventional registries for carbon offsets, such as e.g. national registries, the International Transaction Log (ITL) or CDM registries under the Kyoto Protocol, or registries for voluntary carbon standards such as Verra or the Gold Standard are database applications that allow authorities as well as project participants to track offset projects and issuance of offset credits for each unit of emission reduction or removal that is verified and certified under a given standard. They usually work with user accounts, recording the ownership of credits and a unique serial number is assigned to each credit in order to guarantee identification and as a way to omit double counting. When a credit is sold and transferred, the serial number for the unit is transferred from the account of the seller to an account for the buyer. If the buyer "uses" the credit by claiming it as an offset against its own emissions, the registry retires (or cancels) the serial number so that the credit cannot be resold. In this manner, registries reduce the risk of double counting (Carbon Offset Guide).

The bottom-up approach of the Paris Agreement's Article 6 market mechanisms requires Parties unilaterally to "ensure environmental integrity and transparency" and to "apply robust accounting" to ensure, inter alia, the avoidance of double counting. Compared to the earlier Kyoto mechanisms, Article 6 poses significantly more complicated accounting challenges due to the heterogenous accounting systems and rules, as well as greater need for transparency

(Schletz 2020, Schneider, Fuessler et al. 2017). A re-design instead of an incremental improvement of the system might be needed. Blockchain technology/ DLT, which constitute and innovative approach to accounting and data harmonization, has the potential to overcome these challenges (Schletz 2020).

Having said this, it is important to build on the experience and improvements that earlier registry systems provided, e.g. in terms of their user friendliness, reliability and vulnerability to fraud. Blockchain/ DLT based registry systems are an option to overcome some of the challenges experienced by earlier systems and may be more adequate for a more decentralized Article 6 world.

Blockchain technology in a nutshell

In a simplified view, the blockchain can be seen as a new kind of database system that does not follow a centralized structure like conventional databases (e.g., to track transactions of values on a central mainframe computer in a bank) but dispersed over many decentralized computers (termed “nodes”, “validators”, or “miners”) in what is called a “distributed ledger”. Each ledger contains an exact copy of the entire database, and each new entry into the database is to be verified decentralized by all the nodes, and, once approved by the entire network, stored in all the ledgers.

Another key element of the blockchain technology is the cryptographic architecture that “chains” each new entry or “block” of data in the database to earlier entries. Each new entry contains a short but unique digital fingerprint (“hash”) of the data block before. In this way the entries of earlier blocks cannot be changed anymore providing security and transparency over earlier entries.

Every network based on blockchain technology is run by a protocol which sets the system’s rules. These rules are binding to all parties. The infrastructure of a blockchain network consists of many individual nodes. These nodes interact permanently adhering to the protocols’ rules. By means of blockchain technology, transactions can be verified, validated and linked to each other, for example, by using transaction blocks—the origin of the term blockchain. This leads to a history of transactions in subsequent data blocks (transactions “chained” together) shared by the whole network (CLI 2018b).

The core of every blockchain network is powered by its consensus mechanisms. Consensus mechanisms ensure that all participating computers in the network apply the same principles and functioning when working on the state of the network. Providing for a consensus among the nodes is crucial for every decentralized blockchain network.

The nodes in blockchain networks are constantly crosschecking against each other. A planned transaction is first determined by multiple nodes as correct and then ticked off. Hence, a transaction is only qualified as correct if each evaluating party concludes that the transaction was created in line with the applicable protocol rules. If most of the parties consider the transaction to be correct (by applying a consensus mechanism) the transaction together with a series of other transactions is merged into a cryptographic code and built into a block. This block is appended to the previous block in the blockchain (CLI 2018a).

As the blockchain expands at a linear rate, tampering with one block in the chain would also require adjusting the hash of all subsequent blocks. This tamper-resilience of historical transactions is particularly relevant in the auditing context. Immutability has the advantage of bringing consistency into the history of an asset such as an ITMO. In a blockchain based immutable system every single transaction can be traced back which prevents certain kinds of fraudulent behaviors (Schmetz et al. 2020).

Blockchain technology is only one type of the much broader concept of distributed ledger technologies (DLT), which generally denotes any decentralized database of replicated, shared and synchronized digital data spread across multiple nodes for multiple participants that e.g. do not necessarily need hashing. For instance, IOTA is a DLT using “Tangle” rather than a blockchain approach (i.e. two or more blocks are used for the calculation of the next block, deviating from the initial concept of a linear “chain”).

The flavors of blockchain/ DLT and its relevance for Article 6 registry architecture

Blockchain networks/ DLT can be **public or private** (see Table 2). To put it simple, public blockchains/DLTs are the “pure” blockchains/ DLT, where anyone can participate and play any part including being validator and writing to the blockchain/ DLT. Private blockchains/ DLTs may be positioned somewhere between the “pure” fully public blockchain/ DLT and conventional databases, where participation and activities are entirely centralized and governed by one or few entities. A relevant distinction is the fact that public blockchains/ DLTs by definition do not require the identification of participants. The cryptocurrency Bitcoin is an example of a public blockchain and is known to identify merely subscriber pseudonyms. In the context of registries that run under national and international regulatory frameworks however, and where each international transfer has to be authorized by the host country authority, it is important for governments to be able to clearly identify participants and to restrict access to the registry to eligible entities. From a governmental perspective, it seems therefore to be logical to focus on private blockchains/ DLTs for electronic registry systems.

Also from the perspective of private sector participants, fully public blockchains/ DLTs may not be an option since companies are often asked to obtain information about their trading partners for compliance reasons (for example due to compliance requirements such as "KYC - Know Your Customer" provisions). (CLI 2018b)

An other benefit of private blockchains/ DLTs is that they are usually faster and more efficient because they can circumvent the need for proof-of-work / proof-of-stake and the role of validators. For instance, private blockchain systems/ DLTs may agree in a consortium that nodes are selected randomly to carry out validation and writing of new blocks rather than through an energy intensive proof-of-work mechanism.

Table 2. Key characteristics of private versus public blockchains/ DLTs

	Private blockchain/ DLT	Public blockchain/ DLT
Main features	• Permissioned blockchain/ DLT • By invitation only • Privacy guaranteed • Only selected nodes can read and write	• Permission-less blockchain/ DLT • Anyone can join • Anonymity guaranteed • Any node can read and write • Security achieved via consensus mechanism (proof of work, proof of stake)
Benefits	• Protecting IP and commercially sensitive information • Different types of users may be differentiated (multitenancy)	• Security • Full transparency
Limitations	• Lower level of security	• Speed, capacity • Users are equal and need identification/ wallet system

Source: Adapted from CLI 2019.

To maximize transparency and accountability, a public system, where all data are available, could be seen as the best solution. However, it is uncertain at this point if all national Parties are willing to disclose all mitigation action data. Privacy issues may be a hindering factor for the implementation of public blockchains/ DLTs in carbon markets (Schletz et al. 2020, CLI 2018a).

Automation via **smart contracts** implemented on a distributed ledger is a further option when establishing cooperative approaches and registries. Smart contracts can be understood as computer programs on a blockchain/ DLT representing legal contracts, e.g. that automatically pay the seller according to the purchase agreement when the emission reductions arrive in the buyers account. Such smart contracts are immutably integrated in the fabric of the blockchain/ DLT and may therefore provide an additional layer of trust to the parties in a purchase agreement.

In defining smart contracts on a blockchain/ DLT, the Parties retain full liberty in designing the terms of the relationship of international transfers under Article 6 and other legal elements in a fully human-readable format. Smart contract templates could be developed under the UNFCCC or by other program standards to facilitate deployment of compliant national and/or regional registries, including the registry of the mechanism under Article 6.4, and to facilitate interaction with the registries of other market-based mechanisms in the United Nations system, regardless of whether or not they use blockchain/ DLT for their internal functioning (CLI 2018a).

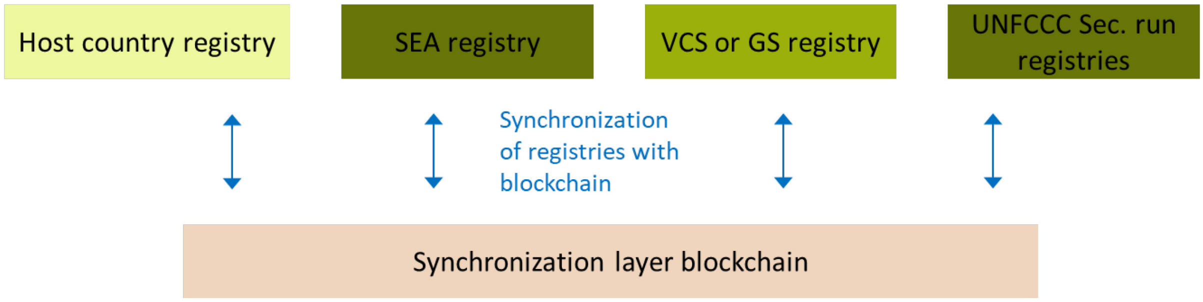
Compared to a conventional centralized database system, blockchain systems/ DLTs in general are characterized by a lower transaction throughput, limiting the amount and speed of data stored on-chain, because any modification needs to be propagated through the entire decentralized network rather than only in the central database. Also, consensus mechanisms require significant time and resources. In sum, this is often described as the **blockchain scalability issue**. The storage of larger files and pictures poses a challenge to most blockchains/ DLTs as it increases data synchronization volumes (Schletz et al. 2020). With larger datasets, blockchain technology/ DLT faces technological restrictions and users may therefore turn to conventional databases and store only a fraction of the database in the blockchain/ DLT to maintain some of its security and transparency benefits. Scalability appears to be a technical challenge which may be solved via approaches such as "**second layer** solutions" or "off-chain transactions" (CLI 2018a). The approach seeks to scale blockchain/ DLT transaction capacity while retaining the decentralization benefits of a distributed blockchain/ DLT. It relies as a base layer on a distributed system such as Ethereum that assures security and immutability. This base is complemented by a more performant second layer in order to decrease the burden for the base layer root system[9]. By offloading transactions from the base layer onto second layer platforms ("off-chain"), the blockchain/ DLT network can process transactions at a significantly higher rate. Also, it minimizes the amount of data storage on the base layer and allows for large storage capacity on the second layer. The base layer forms still the immutable basis that can be used as arbiter in case that data is disputed. Second layer solutions are under rapid development and broadly accessible solutions are expected soon.

3.3 Hybrid approaches and using blockchain/ DLT as a synchronization layer

Hybrid applications where a digital fingerprint, i.e. a "hash" of a snapshot of a conventional registry database is regularly stored on an underlying blockchain/ DLT could be an interim "hybrid" option to make the most of the potential of blockchains/ DLTs at this point in time. Such a hybrid approach might also overcome the scalability issue.

In the context of seeking interoperability and consistency between multiple registry systems, an approach might be to create a blockchain/ DLT based synchronization layer that contains the full mapping of several registries that are part of a "club" of registries (Figure 2).

[9] See e.g. https://golucidity.com/layer-2-blockchain-technology/



Source: Authors own analysis.

Figure 2 – Illustration of an underlying blockchain/ DLT serving as the synchronization layer of different registry systems.

Here, the blockchain/ DLT synchronization layer serves as a secure, immutable log of all registry activities in the participating registries. For instance, if a request for a transaction would be made in a host country registry, the registry would first check with the synchronization layer if the transaction would be consistent with all other entries of the registries, e.g. that the same ITMO has not already been transferred to another account. If the synchronization layer approves the transfer, then it is recorded in the synchronization layer and the host country registry and all other registries are automatically updated. In case of disputes, the synchronization layer blockchain/ DLT serves as the reference entry.

Such an approach would give stake in ownership to all the participating registries. It would be possible to change the registries (top) while keeping a secure ledger of transactions. The technical details of synchronization and the interval of updating would need to be developed further.

3.4 Options on how to organize and integrate blockchain/ DLT systems

This section provides an overview of different options on how to organize and integrate one or several blockchain/ DLT systems to work as a transaction ledger and synchronization layer. It is based on work by the Cosmos team and the outcomes of the SEA workshop of August 18, 2021.

Table summarizes key strategic options for the use of blockchains/ DLTs and notes the findings on their pros and cons from the workshop.

Table 3. Key strategic options on how to organize and integrate blockchain/ DLT systems for registries

Strategic option/ description	Pros	Cons
1. SEA owns and operates **own Blockchain/ DLT**. SEA mandates that participating standards and host countries build against its blockchain/ DLT. SEA builds a registry atop the blockchain/ DLT.	• SEA blockchain/ DLT might meet a high level of trust	• Less sovereignty/ ownership for other participating countries • Would the blockchain/ DLT operated by SEA then be more correct than host country registries? HCs are effectively undermining their own systems • SEA on its own may not need Blockchain/ DLT
2. SEA, host countries and other partners form a **Blockchain/ DLT Consortium**. The consortium may include other host and acquiring countries, standards, institutions, MDBs etc. and collectively owns and manages their own blockchain/ DLT (or blockchain base layer).	• Host country and partners are included in running the blockchain/ DLT • Fosters cooperation and trust • Blockchain/ DLT can be privately managed, inclusive to the consortium	• Require that other actors take part in the consortium and agree on joint rules, which may increase transaction cost or prove difficult for LDC (capacity building needed)
3. SEA partners with an **Independent Institution** to act as the secretariat. Here, the secretariat would be responsible for maintaining a central registry (or base layer blockchain/ DLT) and propagating all transactions to SEA and its Host Countries via integrations. Examples for potential institutions: Verra, Gold Standard, Markit, etc.	• Lower administrative cost for SEA • Developed market of registry service providers	• Dependent on providing institution • Limited impact of SEA and partners on design and architecture of registry solution
4. SEA relies upon a **Third Party Private Blockchain/ DLT** Technology Platform (e.g. Ethereum, …)	• Use work from existing huge players, trusted technology • Interoperability should be good as long as the blockchain/ DLT is large enough • Compatible with Option 2 and 4, but pushes the infrastructure management to the third party provider.	• Dependent on providing institution • Interoperability may be restricted to the provider's partners • Less ownership for SEA
5. SEA builds upon a third party **Public Blockchain/ DLT** (e.g. Ethereum)	• Countries don't need to host blockchain/ DLT infrastructure	• See issues with purely public blockchains/DLT raised in section 3.2 • There are questions about the robustness, security

Strategic option/ description	Pros	Cons
		and environmental footprint of existing public blockchains/ DLT[10]

Note: Options are not always mutually exclusive but can be combined.
Source: Contributions from participants of SEA workshop of 24th August 2021 and own analysis.

Another concept not included in Table 3 is the Climate Warehouse[11] of the World Bank. This is not a registry, but rather a blockchain based meta-database extracting and bringing together publicly accessible information from different registries in one system. This does not allow for registry functions such as transfer and cancellation of units, but for analysis, e.g. the warehouse may be able to flag risks of double counting within the participating registries.

4. Working together: how to develop an international Article 6 infrastructure

4.1 Challenges for linking registry systems and solutions

Blockchain/ DLT based registry systems may better match the de-centralized architecture of the Paris Agreement and be accepted by a wider range of countries

The Article 6 system of cooperative approaches is expected to be much more heterogenous than the old Flexibility Mechanisms under the Kyoto Protocol (Clean Development Mechanism, Joint Implementation, International Emissions Trading), where international transfers were carried out under the centralized supervision of the UNFCCC and its bodies (Fuessler and Herren 2015).

Registries based on blockchain technologies/ DLTs lend themselves as a viable approach, as a de-centralized approach is so to speak "backed-in" the technology of the registry infrastructure. This may be appealing in particular if the blockchain/ DLT registry is to handle the trusted data of a whole set of different stakeholders, governments and private sector actors.

However, it is important to highlight that also in the heterogenous market environments of Article 6, the use of conventional centralized registry databases is a feasible option, if robust trust and governance systems can be built on a (non-technical) level. In this case however, the trust between actors in the reliability of the system is not provided by the technology per se, but by trust in a centralized institution that operates the registry. Such a conventional registry database system could also be combined with digitized or even blockchain/ DLT based MRV

[10] May be addressed by new version of Ethereum due in 2022. See https://ethereum.org/en/eth2/

[11] https://www.worldbank.org/en/programs/climate-warehouse

systems (Section 3.1). A current example of this approach is the European Union Transaction Log (EUTL). The EUTL is a central transaction log, run by the European Commission, which checks and records all transactions taking place within the trading system. Here, the European Commission plays the role of the trusted centralized guarantor of trusted data and governance[12].

Assuring interoperability and becomes essential for functioning international Article 6 markets

In the emerging world of Article 6 cooperative approaches, it may be expected that different countries will agree on different approaches, governed by different program standards and using different digital systems, databases and protocols for MRV and a multitude of different registries, because the earlier central rule-setter, the UNFCCC and its bodies, has a much weaker role.

In this situation, interoperability between the different systems becomes an essential element of any functioning international Article 6 markets, as only interoperability can achieve a de-fragmentation and higher liquidity of the markets. Interoperability covers more than just technical hardware or data and format standards. According to the United Nations Statistics Division, four layers of interoperability may be distinguished (for a more detailed discussion see Sections 2.1 and 2.2 in CLI 2020):

[12] Please note that also the EUTL had repeated issues of fraud and the safeguards have been continuously improved over time. In general, the fraudulent attacks were carried out though the national registries and their administrator systems. In general, any registry system building on data from different contributors is only as strong as its weakest contributor. This holds also for blockchain based registries.

Table 4. Overview on layers of interoperability

	Requirements	Best practices	Examples
Technology	The hardware and the code must allow one system to connect to another and share data.	Technological interoperability through agreed-upon interfaces	Application programming interfaces
Data and format	Exchange of data must be enabled through common data formats defined for data encoding, decoding and representation.	Adoption of common data and metadata models	Data exchange standards for the UNFCCC International Transaction Log
Human	Users and producers of data must have a common understanding of the terms used to describe data contents and proper use.	Use of controlled vocabularies and classifications to standardize content	Agreement between partners on World Bank warehouse prototype pilot
Institutional and organizational – governance	Allocation of responsibility (and accountability) for data collection, processing, analysis and dissemination both within and across organizations must be clear.	Enabled by legislation or by conclusion of data-sharing agreements, licenses and memorandums of understanding	Legally binding elements of the regulatory framework of the EU Emissions Trading System

Source: Adapted from United Nations Statistics Division, as cited in CLI 2020

Please note that interoperability does not automatically mean the full fungibility of mitigation outcomes between different systems. As it may not be expected that the quality of mitigation outcomes will be determined with sufficient stringency by the rules of the UNFCCC and its bodies, it will be important for some host and acquiring countries to adhere to stringent quality standards assuring minimum levels of environmental integrity of mitigation outcomes and sustainability benefits of the related mitigation interventions, while other countries or other actors will put less emphasis on quality and more on the low cost of mitigation outcomes. To put it simply, interoperability does not mean to allow the fungibility of high quality with low quality units, but to foster the international transfer of mitigation outcomes between different systems of which the participating countries and other actors in a "club" or "consortium" agree on the equivalence in quality of their respective units.

Blockchain/ DLT registries may foster interoperability

With the use of smart contracts (Section 3.2), blockchain/ DLT can for instance facilitate the restricted transfer of units between market systems with different metrics for mitigation outcomes. For instance, outcomes that are measured in kilowatt-hours (kWh) of renewable energy supplied to the grid in a specific country in one system can be translated from kWh to emissions in tonnes of CO_2 that may be the metric of another system. The smart contract would use agreed rules to determine the relevant baseline grid emission factor.

Or, one market system/ program standard may only allow the influx of mitigation outcomes from other systems if the units themselves meet the (more stringent) quality criteria of the system. Here, smart contracts could automatically check the eligibility of mitigation outcomes if a request for transfer is triggered, functioning like a kind of "valve" to assure the quality of mitigation outcomes that are traded within the system (see also the concept of an International Carbon Asset Reserve in Fuessler et al. (2015) and (2016)).

Interoperability between registry and MRV systems – including the last mile issue

A particular area of concern in automated MRV is the "last mile issue", i.e. the question, how to assure the save and uncorrupted transfer of data from the "oracle", i.e. a data source outside the blockchain/ DLT such as a certified gas meter in a landfill gas project, to the blockchain/ DLT. Here, encrypted data transfer may be used, as has been demonstrated in a recent Prototype system by the World Bank Carbon Markets and Innovation Practice (CMI) and Technology and Innovation Lab (ITSTI) (CLI Navigating Report 2019, section 3.2).

As it is assumed that different MRV, tracking and registry systems may emerge over the next years for Article 6 activities, the concept of interoperability becomes key to assure that different systems – registries and MRV systems – can talk to each other. Here, different technical approaches may be considered. A first overview of different approaches to enable interoperability is provided in Table 5.

Table 5. Main approaches to allow for interoperability between MRV and registry systems

	Description	Pros and cons
Cross-authentication	Allows different blockchains/ DLTs to plug into a larger standardized ecosystem via hash locking – setting up operations on blockchain A and blockchain B with the same trigger – the most practical method for interoperability in cross-authentication but limited in functionality, supporting only digital asset exchange	Pro: Only approach that can enable blockchain/ DLT interoperability without using a trusted central party Con: Limited practical experience – technology not yet widely adopted
Oracle	Transfers external data to the blockchain/ DLT platform for on-chain use; can be used to automate processes based on real world events, such as the automated indemnification of climate risk crop insurance	Pro: Proven and easy to implement systems; provides data feeds about external events Con: Does not create actual blockchain-to-blockchain interoperability; makes blockchains/ DLTs interoperable with their (non-blockchain) environment
API Gateway	Governs the access point to a server and the rules that developers must follow to interact with a database, library, software tool or programming language; organizes several APIs	Pro: Tried and tested technology – easy to implement Con: May not guarantee data consistency across two blockchain/ DLT platforms, i.e. may not guarantee

	Description	Pros and cons
		that updates are made to a given data item; centralizes trust in API operators

Source: World Economic Forum (WEF) as cited in CLI 2020, section 2.2.

From verifying mitigation outcomes to verifying systems

In the medium term, digitized MRV can lead to a situation where third party verifiers move from verifying monitoring data to verifying monitoring systems (e.g. from smart meters, IoT, data transfer to smart contracts on the blockchain/ DLT, automatically calculating the emission reductions according to the "digitized methodology" and issuing units into the registry). This will probably only be realized at a later stage but illustrates the potential of the technologies to drastically reduce transaction costs, particularly to lower expensive verification costs.

Governance on all levels is key

Governance considerations such as the allocation of power, risks and responsibilities are core to blockchain/ DLT based climate actions. Governance challenges occur on the international, national and blockchain/ DLT level. While the focus of the first two levels is on complying with existing national and international laws, the latter is about actively defining rules that will then be automatically enforced (for a detailed discussion of governance issues on all these levels, see CLI 2021).

4.2 Preliminary view on strategic options for international collaboration

In a technical workshop with SEA staff and study authors on August 24th, 2021, different potential strategic options for international collaboration have been discussed and evaluated. There are different objectives for SEA to invest in the digitalization of its Article 6 infrastructure. Sweden wants to start implementing Article 6 pilot projects and a reliable infrastructure to track the international transfer of ITMOs needs to be ensured. The advantages of being an early mover lie in making a positive influence on international markets and the development of sound and trusted rules, institutions and infrastructure. From this, the SEA team developed to the following five main objectives, fostering its efforts in advancing a digital Article 6 infrastructure:

- **Fostering climate action in developing countries:** The promotion of climate action in developing countries is one of SEA's key interests and can be supported and promoted by a well-functioning registry system.
- **Efficient purchase of mitigation outcomes**: The efficient processing of transactions is important for SEA, which also means that ITMOs can be transferred cost-

effectively. However, SEA seeks to acquiring quality units and not primarily the cheapest ITMOs but making the processes efficient is a key objective.

- **Develop a sound system to ensure environmental integrity:** The purchase of mitigation outcomes with high environmental integrity is per se a goal of SEA, which can be partly assured by a well-functioning registry system.
- **Ensure transparency:** A digital registry system that increases the transparency of transactions fosters accountability towards its stakeholders and contributes to achieving the transparency targets set by the UNFCCC.
- **Evidence for real transactions:** As Sweden wants to implement Article 6 pilot activities soon, there is an interest in having a functioning registry system so that the generated mitigation outcomes can actually be transferred.

In order to achieve the objectives outlined above, three main strategic options are conceivable and feasible as summarized in table 5.

Table 6. Possible strategic options to reach the objectives of developing a digital article 6 architecture.

Strategic option	Pros	Cons
1. Build an own infrastructure	• SEA can find the design which suits best and; • Tailor the architecture to SEA's needs. • Generate the potential to accelerate best practice infrastructure systems, waiting for others to join may slow down the process.	• Needs a lot of resources from SEA side. • Insecurity about the institutional setting creates potential risks (risk that the registry will not be compliant). • Lack of technical expertise at SEA.
2. Wait and see strategy	• Less costly	• ITMOS could not be transferred as SEA is an early mover. • SEA could not have a positive impact on how MRV would be implemented.
3. Focus on collaboration	• Not reinventing the wheel is important to SEA as it helps also to be more cost-efficient. • It can help leveraging SEAs activities and can bring synergies. • It enhances the likelihood to produce a long-lived registry architecture.	• It takes time and resources; • SEA may need to compromise on plans and structures.

Source: Results from the SEA workshop of 24th August 2021.

The Article 6.2 rulebook (out of COP26) tasks the UNFCCC Secretariat to create an international registry for Article 6. Countries should have access to a registry and could choose to use the UNFCCC international registry platform, create their own national registry, or use the registry of an existing independent or international crediting program. The host country should report these arrangements to the UNFCCC. One important challenge in relying on the UNFCCC registry is that this may still need some time to develop including the related institutional arrangements in the UNFCCC Secretariat for Article 6.

As Sweden is already well advanced with the piloting of Article 6 activities and wants to start implementing activities and hence transaction of mitigation outcomes will become reality soon, a wait and see strategy is not an option for the team. SEA needs to build up its own infrastructure, but also wants to build on cooperation with like-minded partners in order to enhances the likelihood to produce a long-lived registry architecture and making use of synergies. Potential partners include other early mover host and acquiring countries, but also private program standards such as Verra/VCS and the Gold Standard.

Furthermore, there are two strategic options which are important to SEA and can be implemented to complement options 1 and 3 in Table 5:

- **Empowering host countries:** Many developing countries have limited capacities and resources for infrastructure for MRV and registries. The use of blockchain technologies/ DLT and digitized MRV is particularly rewarding for countries where the governmental systems tend to be rather weak and trust in data needs to be built. Investing in infrastructure in Article 6 host countries may be a strategic move to increase their readiness for the Article 6 market mechanisms.
- **Incorporating the private sector:** Post 2020 the private sector emerges as an increasingly strong partner for implementing (and tracking) mitigation action. Working with the private sector may help to create a demand for MRV and tracking services early and develop the infrastructure faster. Hence, SEA perceives it's important to take private sector on board from an early stage. This may lead to better transparency and provides the potential for future up-scaling, also across different sectors. In order to incorporate the private sector it's important to be able to rely on trusted registry systems.

This preliminary overview of strategic options may support for future strategic decision at SEA.

5. Findings and preliminary conclusions

Any cooperative approach under Article 6 requires the establishment of robust institutional settings, regulatory frameworks and reliable and trusted information systems in the form of a registry. Such a registry system has to track mitigation outcomes along the process cycle of ITMO transfers, including authorization, measuring, reporting and verification (MRV), issuance, transfer, corresponding adjustment, cancellation, etc.

The use of a decentralized blockchain, or more generally distributed ledger technology (DLT), and other digital innovations for electronic registry systems and MRV may provide numerous benefits compared to the use of a conventional centralized database. They include increased security, as blockchain/DLT entries are immutable and therefore provide for additional trust, which may be particularly important in the context of countries with weaker institutional capacities and governance settings. Also, the digital technologies provide for additional levels of automatization (e.g. in "smart contracts") increasing not only trust in the functioning of the system but lead also to efficiency gains in the project transaction cycle. Blockchain/DLT systems may also be better suited to connect different registry systems and thus allow for the linking of a multitude of heterogenous carbon markets.

However, depending on the technology used, blockchain technologies/ DLT may also have limitations compared to conventional databases, including lower transaction speed and capacity, and high power consumption and transaction costs (depending on the consensus mechanism[13]). Approaches to overcome these shortcomings include, for instance, hybrid approaches, combining conventional databases with an immutable blockchain/DLT layer.

Please note that the present study has been elaborated before the adoption of the Article 6 rulebook at COP 26 in Glasgow in November 2021 and therefore it does not provide specific guidance on the newly defined *international registry*, the *Article 6 database* and the *centralized accounting and reporting platform* as well as the (Article 6.4) *mechanism registry*. Our findings also hold in the context of the newly defined Article 6 registry infrastructure.

The following findings and preliminary conclusions are based on an initial analysis of the requirements of future Article 6 registries, the experience from the coding of a simple registry system by IT partner Cosmos, and a technical workshop with the SEA and project team:

- If SEA wants to implement the registry system focusing purely on its domestic needs, then a conventional database may be a better solution. Such a system may be locally efficient and, in a domestic system for Sweden, public trust in government and public databases is high enough that there is no need for a technological trust layer trough blockchain/DLT.

[13] In simple words, the «consensus mechanism» is the process with which the system decides which node is allowed to add the next data-block to the blockchain. In the Proof of Work approach, node that first solves a cryptographic puzzle using a lot of processing power and energy is allowed to add the next block to the chain.

- On the other hand, cooperation between countries is efficient in climate action and helps building an Article 6 community of partners. Sweden, as an internationally well respected and neutral country, may together with similar minded countries form the nucleus of an international Article 6 registry and transaction infrastructure that can attract many other countries to join based on its usefulness, trusted technology and high environmental integrity.
- As Sweden is already well advanced with the piloting of Article 6 activities and wants to start implementing activities and transacting mitigation outcomes, a "wait and see" strategy is not to be an option for SEA.

From a technical point of view, the following preliminary recommendations are made based on the analysis:

- In order to start developing concepts for a joint approach to developing Article 6 registry infrastructure, it is important for SEA to learn more about the specific needs and expectations of host and acquiring countries, and other partners, including in terms of technological functionality, standards, as well as governance and readiness to share sovereignty with partners.
- If SEA seeks to work in cooperation, then blockchain/ DLT has numerous benefits and can be implemented such that potential limitations (e.g., capacity, power consumption, transaction cost) can be largely overcome.
- The blockchain/DLT would be owned and operated by a consortium of partners which may include other host and acquiring countries, standards, MDBs etc.
- From the limited analysis of this study, a private permissioned blockchain/DLT operated by a defined consortium may be the optimal solution for backing a registry system. This solves issues with governmental oversight and can be better aligned with existing national and international regulations. In addition, it does not require energy intensive consensus mechanisms and does not need to rely on a major third party blockchain/DLT operator.
- In order to be able to handle the required number of transactions and provide enough data storage e.g. to document additional attributes of ITMOs (including e.g. sustainability benefits), a hybrid system may be an optimal solution. This would combine
    - a conventional database containing the main data of the registry including on mitigation activities and units,
    - a blockchain/DLT system containing a hash (i.e. a "digital fingerprint") of the overarching database, that can be used to assure the trustworthiness of the data.

  Other approaches may include advanced concepts of second layer blockchain/ DLT systems, which seem not yet sufficiently developed.

- A specific approach to a hybrid solution would be that the consortium owns and manages an underlying synchronization layer blockchain/ DLT (see Figure 2). This common synchronization layer serves as a secure, immutable log of all registry activities in the participating registries of the consortium members.

Once the technical and institutional specifications are further developed it is advisable to clarify the specific blockchain/ DLT type that is most suitable for the required registry system. Also, at that stage, the pros and cons of blockchain/DLT based systems should be carefully reassessed against conventional database solution where trust is less based on (blockchain/ DLT) technology but on the institutional level (e.g. similar to the existing UNFCCC CDM registry).

In any case, while it appears that there is sufficient interest from different parties and organizations in a joint and coordinated approach to an Article 6 registry and transaction system, it is important to start early with discussions with potential partners in order to reach an agreement on jointly developing a robust pilot system.

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