Public Disclosure Authorized
Public Disclosure Authorized
Public Disclosure Authorized
Public Disclosure Authorized

# Digital Monitoring, Reporting, and Verification Systems and Their Application in Future Carbon Markets

June 2022

PMIF
PARTNERSHIP FOR MARKET IMPLEMENTATION FACILITY

Administered by
THE WORLD BANK
BRD • IDA | WORLD BANK GROUP

THE NETWORKED CARBON MARKETS INITIATIVE

Climate Warehouse

## Acknowledgements

This report was prepared by Lucas Belenky, Keisuke Iyadomi, Susan David Carevic, and Harikumar Gadde of the World Bank's Carbon Markets and Innovation Unit, under the leadership of Wendy Hughes, with support from the Partnership for Market Implementation Facility (PMIF).

The following people provided valuable contributions in their personal capacity:

**Case study participants:** Sven Braden (Wood Tracking Protocol); Michael Fabing (Wood Tracking Protocol); Tom Baumann (Chile case study); Dmitry Halubouski (European Bank for Reconstruction and Development case study); Polly Thompson (Sylvera case study); Sandeep Kanda (India case study); and EY India (India case study).

**Land-use companies and non-profit organizations consulted:** Global Mangrove Trust (Simon Schillebeeckx); Kumi Analytics (Clinton Libbey); Regen Network (Gregory Landua and Ron Steinherz, now an independent contractor); and Pachama (Diego Saez Gil and Marcela Corradini).

**Expert reviewers:** Andres Espejo; Owen Hewlett; Dmitry Halubouski; Tom Baumann; Rachel Mok; Massamba Thioye; and Gemma Torras Vives.

© 2022 International Bank for Reconstruction and Development / The World Bank
1818 H Street NW, Washington, DC 20433
Telephone: +1-202-473-1000
Internet: www.worldbank.org

## Disclaimer

This work is a product of the staff of The World Bank with external contributions. The findings, interpretations, and conclusions expressed in this work do not necessarily reflect the views of The World Bank, its Board of Executive Directors, or the governments they represent.

The World Bank does not guarantee the accuracy of the data included in this work. The boundaries, colors, denominations, and other information shown on any map in this work do not imply any judgment on the part of The World Bank concerning the legal status of any territory or the endorsement or acceptance of such boundaries. All amounts in $ are United States dollars unless stated otherwise.

**RIGHTS AND PERMISSIONS**

The material in this work is subject to copyright. Because The World Bank encourages dissemination of its knowledge, this work may be reproduced, in whole or in part, for noncommercial purposes as long as full attribution to this work is given.

Attribution—Please cite the work as follows: World Bank. 2022. Digital Monitoring, Reporting, and Verification Systems and Their Application in Future Carbon Markets. World Bank, Washington, DC.

All queries on rights and licenses should be addressed to the Publishing and Knowledge Division, The World Bank, 1818 H Street NW, Washington, DC 20433, USA; fax: 202-522-2625; email: pubrights@worldbank.org.

Editing and design by Clarity Global Strategic Communications (www.clarityglobal.net).

# About this report

The purpose of this technical report is to illustrate the need for digital monitoring, reporting, and verification (D-MRV) systems to underpin future carbon markets under the goals of the Paris Agreement by discussing the available technologies and barriers to their adoption. It includes guidelines, tools, and lessons learned to promote the use of these systems and emerging technologies.

Section 1 of the report makes the case for transitioning from a conventional monitoring, reporting, and verification (MRV) system to a D-MRV system. It examines the various types of D-MRV, the barriers to implementing a D-MRV system, and the benefits of overcoming these barriers. It also examines the resources needed to develop and implement a D-MRV system, and what an enabling policy and regulatory environment for D-MRV systems might look like. Finally, it suggests a tool for assessing whether a parameter can beneficially be monitored and reported under a D-MRV system.

Section 2 offers case studies from across the world demonstrating how D-MRV systems can be used to monitor, report, and verify mitigation actions and greenhouse gas inventories linked to forestry and land-use projects, household and rural renewable energy projects, and even waste-to-energy projects. The case studies include lessons learned and best practices for developing, implementing, and managing a D-MRV system.

# Executive summary

Post-2020 markets under the Paris Agreement will be built through a bottom-up approach, as each party to the Agreement is required to track the greenhouse gas (GHG) emission reductions (or removals) achieved—and has considerable leeway to determine how this will be done.

The bottom-up nature of future carbon markets comes with increased complexity and diversity of reporting and verification approaches for GHG emissions inventories and mitigation outcomes. There is significant potential for digital monitoring, reporting, and verification (D-MRV) systems to underpin and streamline the functioning of post-2020 carbon markets.

The current methods to report GHG emissions and validate or verify emission reductions can be costly, error-prone, and time-consuming, often relying on manual processes and in-person surveys. Increasingly, digital technologies are used to streamline data collection, processing, and quality control in monitoring, reporting, and verification (MRV) processes. Examples of such technologies include smart sensors, satellites and drones, cloud computing, artificial intelligence, the internet of things, and blockchain encryption. Further, D-MRV systems can be applied across the commonly defined MRV types: MRVs of GHG emissions, mitigation actions, and support.

Transitioning towards the use of credible and compatible D-MRV systems to track GHG emissions, as well as the generation of mitigation outcomes, will improve the functioning, enable scaling-up, and increase transparency of post-2020 carbon markets.

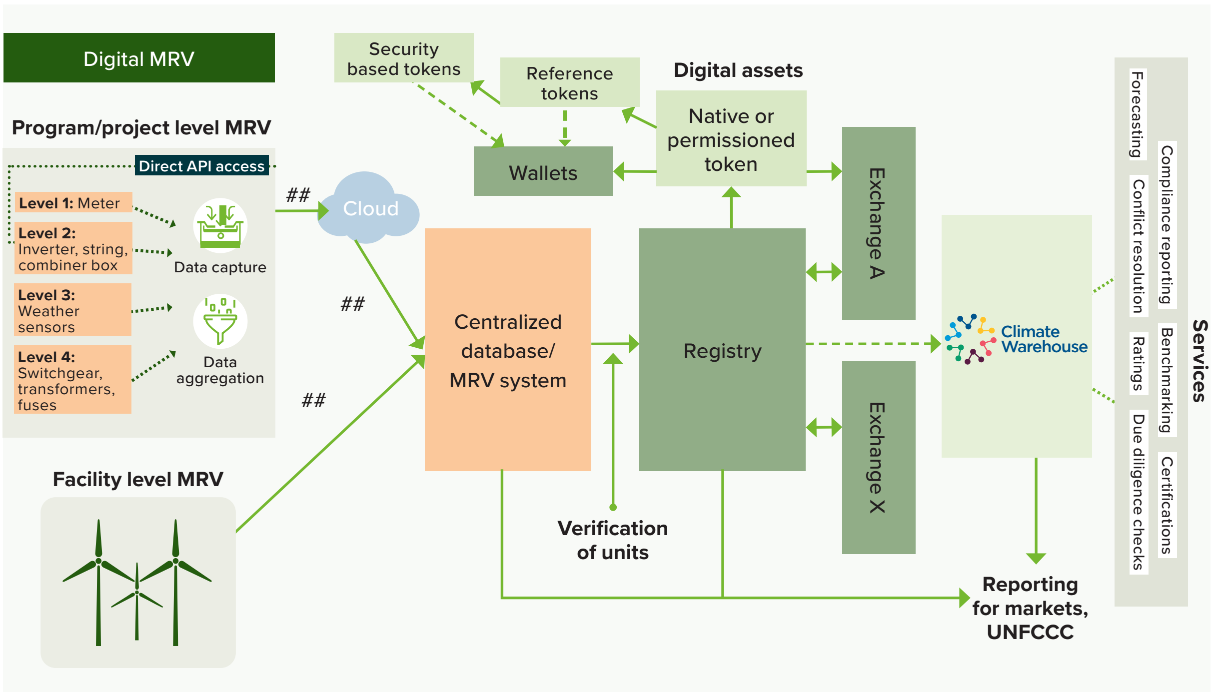
D-MRV systems are one component in the end-to-end digitalization of the generation, transfer, and reporting of carbon assets under post-2020 carbon markets. In addition to using emerging technologies to improve data collection and verification, D-MRV systems can be connected to national or global registries to automate fulfillment of reporting requirements. Figure 1 shows how D-MRV systems fit into this ecosystem.

The use of blockchain technology to create immutable and auditable data and transfer records, including the creation of mitigation outcomes in digital form underpinned by smart contracts, is another important component of end-to-end digitalization of carbon markets that the industry is designing and implementing.

Many partially or fully digitalized MRV systems are being piloted or implemented in different countries and across various sectors. This report includes case studies on selected pilot D-MRV systems, providing a useful record of insights and lessons learned to promote the further use of digital technologies. The systems examined in the case studies cover forestry, waste, and energy projects in South America, the Middle East, Asia, and Africa.

Multiple barriers need to be removed to enable the widespread use of D-MRV systems. As some of the case studies show, the funds and expertise required to implement these technologies for a new D-MRV system, or to upgrade an existing MRV with these technologies, are often prohibitive. D-MRV systems also sometimes capture sensitive data (for example, a mitigation action MRV covering household appliances or decentralized energy generation may

FIGURE 1: END-TO-END DIGITALIZATION OF CARBON MARKET INFRASTRUCTURE[1]




store personal customer information), necessitating additional privacy controls to be put in place. Finally, there is little familiarity of emerging digital technologies, especially in developing countries, so knowledge-sharing and capacity-building efforts are crucial. The latter is especially important to ensure equitable access to carbon markets, particularly in areas where capacity for innovative approaches is low.

In addition to the barriers listed, the enabling environment for D-MRV systems is insufficient, making the design, implementation, and operation of these systems burdensome and risky. To manage this risk, governments or institutions need to develop policies or guidelines that clearly state how sensitive information may be collected, used, and stored. Governments also need to ensure that the required infrastructure, power, and data networks are available for digital technologies to be effectively implemented. Strategic tax incentives might also promote the use of desired emerging technologies.

In addition to these measures, independent standard organizations and regulatory bodies need to adapt their MRV protocols to allow for digitally collected data and establish rules for how these systems are validated and verified. For example, allowing for one-off, on-site validation using a D-MRV system certification, followed by recurring remote verifications, will increase the speed of validation and verification while reducing the overall cost of generating mitigation outcomes and incentivizing the use of digital technologies.

Capacity building, grants, and knowledge sharing for private companies and non-profit organizations implementing D-MRV systems for carbon markets are also needed to overcome initial gaps in financing and technological expertise. This extends to third-party verifiers, who need to develop an understanding of digital technologies so that they can implement revised protocols from independent standard organizations and regulatory bodies.

[1] Sourced from internal World Bank presentation on the Climate Warehouse Initiative.

Building capacity in implementing organizations and verifiers can be achieved by hosting information and training sessions, while “mock” review and certification of pilot D-MRV systems may provide valuable practical insights.

This report proposes a tool for assessing the suitability of monitored parameters for D-MRV systems that might help to create an enabling environment for D-MRV systems and digital technologies. Among other considerations, the tool provides a step-by-step guide for evaluating the need to digitize data collection for a given parameter, whether it is permissible to do so under the chosen monitoring methodology, and if it is cost-effective. Implementing organizations can use the tool to quickly identify any barriers to the digital monitoring, reporting, and verifying of the monitored parameter. The report also sets out commonly monitored parameters, with descriptions of the parameter and appropriate digital technologies, or combinations of technologies, to track these parameters.

D-MRV systems have the potential to make post-2020 carbon markets more streamlined and cost-effective in generating carbon assets and verifying emission reductions—provided there is impetus to overcome the upfront costs and increased technical complexity. However, once these systems are in place, the effort to scale a D-MRV system is much less than a conventional monitoring system.

Creating an enabling environment and further piloting of D-MRV systems will promote continued improvement of emerging technologies while contributing to the knowledge base of D-MRV systems. The full potential of carbon markets to combat climate change can be unlocked through digital technologies and D-MRV systems, setting the stage for future innovations such as the tokenization of carbon assets through blockchain technology, and real-time issuance of mitigation outcomes from projects with system-wide certification of their D-MRV.

# Contents

# List of tables



# List of figures

# Abbreviations and acronyms

| | |
|---|---|
| AI | Artificial intelligence |
| API | Application programming interface |
| CDM | Clean Development Mechanism |
| CONAF | Corporación Nacional Forestal |
| CTF | Clean Technology Fund |
| DISCOMs | Electricity distribution companies in India |
| DLT | Distributed ledger technology (blockchain) |
| D-MRV | Digital monitoring, reporting, and verification |
| EBRD | European Bank for Reconstruction and Development |
| EDIMS | Electronic database and information management system |
| GHG | Greenhouse gas |
| GIS | Geographic information system |
| GRPV | Grid-connected rooftop photovoltaic |
| ha | hectare |
| IoT | Internet of things |
| kW | kilowatt |
| kWh | kilowatt-hour |
| MDB | Multilateral development banks |
| MRV | Monitoring, reporting, and verification |
| MWp | Megawatt-peak |
| NDC | Nationally determined contributions |
| NISE | National Institute of Solar Energy (India) |
| QA/QC | Quality assurance/quality control |
| REA | Rural Electrification Agency (Uganda) |
| $tCO_2e$ | Tonnes of carbon dioxide equivalent |
| VCS | Verified Carbon Standard |
| YDE | Yellow Door Energy Jordan |
| WTP | Wood Tracking Protocol |
| $ | Dollar. All dollar amounts are US dollars unless otherwise indicated |

# Section 1: The case for digital monitoring, reporting, and verification (D-MRV)

## 1 Introduction

International carbon markets under the Paris Agreement are significantly different from those under the Kyoto Protocol. Under the Kyoto Protocol, only developed countries had greenhouse gas (GHG) emission reduction targets, and the protocol defined how carbon units could be traded across countries under international market mechanisms, such as the Clean Development Mechanism (CDM). By contrast, under the Paris Agreement both developed and developing countries are required to submit GHG mitigation goals as part of their nationally determined contributions (NDCs).

Article 6.2 of the Paris Agreement allows countries to partake in voluntary bilateral or plurilateral cooperative approaches to achieve their NDC targets through the transfer and use of mitigation outcomes. NDCs are diverse in nature, with some countries using business-as-usual emissions projections as their reference point, while others use the emissions targets from a baseline year or emission intensity per unit of economic outputs as their point of reference. Furthermore, the bottom-up nature of market mechanisms could generate a variety of mitigation outcomes, which could make it difficult to compare and trade units across different mechanisms, especially when NDC targets are in non-GHG metrics.

The CDM greatly enhanced knowledge about emission reduction project cycles. The protocols, standards, and monitoring methodologies developed under the CDM are likely to see continued use in future carbon markets. However, the CDM's monitoring, verification, and reporting processes—while providing a high degree of certainty that any certified emission reductions are additional, real, and credible—were time-consuming and expensive to implement and validate. Post-2020 carbon markets will need a better way to monitor, report, and verify mitigation activities and resulting carbon emission reductions if these markets are to function properly.

Participants under Article 6 will be required to regularly collect and report data on their GHG emissions and the performance of mitigation activities in their countries, called "collaborative approaches" under the article. The Article 6 rulebook adopted at the 26th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP26) describes the reporting requirements for participating parties. These requirements cover an initial report on, among other things:

- The description of the country's NDC
- A quantification of the mitigation information in the NDC, in tonnes of carbon dioxide equivalent ($tCO_2e$)

- A quantification of the NDC, or the portion in the relevant non-GHG indicator
- A list of proposed cooperative approaches with their expected mitigation outcomes and their alignment with the participating party's sustainable development objectives
- Recurring annual information related to the internationally transferred mitigation outcomes, as well as regular information in an annex to its biennial transparency reports.[2]

Emerging digital technologies such as artificial intelligence (AI), smart sensors, and blockchain could help countries meet those reporting requirements at a relatively lower cost and, potentially, further expand and operationalize market mechanisms such as the one referred to under Article 6 of the Paris Agreement. The use of blockchain technology for digital monitoring, reporting, and verification (D-MRV) systems is explored in the Climate Ledger Initiative's recurring annual report, *Navigating Blockchain and Climate Action.*

D-MRV systems represent the first step in this end-to-end digitalization of post-2020 carbon markets. End-to-end digitalization includes using digital technologies and processes to automate the collection of data, the reporting of GHG emissions, and the generation of mitigation outcomes to improve the functioning of future carbon markets and ease the burden of satisfying reporting requirements under the Paris Agreement. Once D-MRV systems are in place, they can be connected to national or international registries. Tradeable mitigation outcomes can also be tokenized to enable the use of smart contracts.

This report highlights the potential of D-MRV systems, defines the types of D-MRV systems, explains the resources needed to move from a conventional to a digital MRV system and the benefits of doing so, explores the necessary enabling environment, and provides a tool for assessing monitoring methodologies and their suitability for digital technologies.

The report's findings are supported by case studies on D-MRV systems around the world, which are summarized in Table 1 and set out in greater detail in Section 2. These case studies cover different types of mitigation activities, from renewable energy generation to tracking forest growth.

While there are barriers to the widespread use of D-MRV systems, such as the complexity and upfront costs of implementation, the benefits of these systems are expected to be significant. D-MRV systems will reduce the cost of generating carbon assets, increase the transparency and security of carbon market transactions, and even make it possible to tokenize carbon assets; conduct intermittent, system-wide verification of monitoring systems; and move towards real-time generation of carbon credits.

[2] World Bank. 2021. Country Processes and Institutional Arrangements for Article 6 Transactions. Article 6 Approach Paper Series No. 2. World Bank: Washington, DC. [Online]. Available: https://openknowledge.worldbank.org/handle/10986/35392

## TABLE 1: SUMMARY OF CASE STUDIES

| NAME | COUNTRY | STAGE | DIGITAL TECHNOLOGY APPLIED | TECHNOLOGY APPLICATION |
|---|---|---|---|---|
| **Rooftop Solar** | India | Pilot | Smart sensors | Sensor technology measured energy usage, replacing paper processes |
| **Electronic Database and Information Management System (EDIMS)** | Uganda | Operation | Smart electric meters | Smart meters report on pre-paid electricity usage used to calculate consumption for an adapted methodology |
| **Waste to Energy** | Chile | Pilot | Smart sensors, distributed ledger technology | Sensor data secured on the blockchain is provided to Chile's MRV system |
| **Open Surface, Mangrove Trust, Wood Tracking Protocol** | Peru, Chile, Singapore | Various | Blockchain, satellite and drone data, AI | Digital imagery of the forests is analyzed by AI algorithms to identify changes to the forest and conduct remote monitoring |
| **Sylvera** | Global | Operation | Satellite, AI, drones, LiDAR[3] | Using satellite and LiDAR data in combination with AI to rate nature-based carbon credit projects |
| **European Bank for Reconstruction and Development D-MRV System for Renewable Energy** | Kazakhstan, Jordan | Pilot | Smart sensors, cloud computing | Near real-time digital data acquisition and processing in the cloud, immutable storage of raw data, automation of verification process |

[3] LiDAR stands for "light detection and ranging" and involves pointing a laser at an object or a surface and measuring how long it takes for the reflected light to return to the receiver. It can be used to make digital 3D representations of areas on the Earth's surface by varying the wavelength of light.

# 2 Characteristics and types of D-MRV systems

Monitoring, reporting, and verification (MRV) systems have been a core component of the regulatory framework of market mechanisms under both the Kyoto Protocol and voluntary carbon markets. MRV is a term used to describe all measures taken to collect data on emissions, mitigation actions, and support. This includes information on methodologies, assumptions, and data parameters used. Typically, such systems were used both to determine GHG emissions for cap-and-trade systems in Annex I countries, and for mitigation actions in non-Annex I countries to quantify and verify emission reductions under CDM projects.

Due to the bottom-up nature of the Paris Agreement, participating parties are required to regularly submit information on projects and programs related to their Article 6 activities. The reporting requirements are intended to ensure the integrity and transparency of Article 6.2 cooperative approaches. As a result, post-2020 carbon markets will probably rely even more on MRV systems than under the Kyoto Protocol.

Robust MRV systems will be a core component of the infrastructure needed to support post-2020 carbon markets. The World Resources Institute defines three main types of MRV systems:

- **An MRV system for mitigation action** assesses changes in GHG emissions and other sustainable development metrics before and after mitigation action has been taken, or against specific reference levels. This type of MRV can be performed at the national, sub-national, sectoral, organizational, facility, or project level.
- **An MRV system for GHG emissions** estimates, reports, and verifies actual emissions over a period. In other words, it is an emissions inventory. This type of system can be applied at the national, sectoral, organizational, or facility level.
- **An MRV system for support** tracks flows and evaluates the impact of various means of implementation, such as financial support, technology transfer, or capacity building. This type of MRV can be performed at the sub-national, national, or multinational organization level.[4]

Under the Kyoto Protocol, the monitoring, reporting, and verification of GHG emissions and emission reductions was costly and time-consuming, negatively impacting the liquidity of carbon markets. Project data was manually collected and recorded in hard copy or on unsecured electronic worksheets, and verification required on-site inspections by third-party auditors, which could take weeks to complete for projects that involved dispersed technologies in rural areas, such as cookstoves or solar lamps. Private sector project developers typically had to wait two or three years before any emission reductions, or revenue from their sale, could be realized. For smaller projects, the effort and cost of MRV caused long delays in issuing carbon credits, affecting project cash flow. Many of these MRV processes continue today.

To ensure well-functioning, liquid carbon markets under the Paris Agreement, there needs to be a concerted move towards reducing the cost and time needed to certify emission reductions. One way to achieve this is to use emerging D-MRV technologies to streamline MRV processes.

[4] World Resources Institute. No date. 3 Types of Measurement, Reporting, and Verification (MRV). [Online]. Available: https://www.wri.org/data/3-types-measurement-reporting-and-verification-mrv [Accessed April 22, 2022].

## What is a D-MRV system?

Recent technological developments and innovations to reduce the cost of emerging technologies have opened the door to the use of AI, machine learning, satellite imagery, blockchain, smart sensors, the internet of things (IoT), cloud computing, and drones in MRV systems to fully or partially automate data collection, recording, and processing for reporting and verification, which are conducted manually in a conventional MRV. Further digital technologies that could be used in MRV systems, along with potential applications, are presented in a recent Asian Development Bank publication on digital technologies for climate action.[5]

A well-functioning D-MRV system integrates these technologies into a single, overarching system, using common standards of data exchange and application programming interfaces (APIs) to ensure compatibility and interoperability across the different types of D-MRV systems. This interconnectedness allows for another important benefit of D-MRV systems, which is the ability to conduct analysis and infer important insights from data covering multiple similar projects in multiple locations.

D-MRV systems use technology and data-management tools to quantify, communicate, and authenticate outcomes in near real time. They have the potential to improve the speed, consistency, and accuracy of reporting, while lowering reporting and verification costs and increasing the scalability and security of databases. These systems also have modular flexibility, allowing project implementers to develop the monitoring component of the D-MRV and then connect their system to the reporting and verification system of another entity mandated by the government or an international body to oversee reporting and verification. D-MRV systems can also be connected to registries at the sectoral, national, or international level to streamline monitoring, reporting, and verification of GHG inventories or a country's mitigation activities.

Table 2 and Table 3 highlight some of the key differences between conventional MRV and D-MRV systems for GHG emissions and mitigation action. While digital technologies are also being used to bring transparency and efficiency to support MRV processes, this paper does not explore this type of MRV in depth.

The key difference between a conventional and a digital GHG emission MRV system lies in the methods used to collect, process, record, and report on data. Conventional GHG MRVs manually record fuel and electricity usage, which is time-consuming and leaves room for human error. D-MRV systems, on the other hand, collect data in near real time and automate the recording and reporting functions. These systems can be set to flag outliers, making it easier to detect changes in processes, errors in the system, or faulty sensors, providing project developers with the information needed to streamline maintenance.

For mitigation action MRVs, digital systems offer near real-time data collection and automated reporting plus faster and simpler verification of claimed emission reductions.

Mitigation actions cover projects that can be costly and difficult to monitor and verify, such as decentralized, off-grid power generation; efficient household appliances; and forestry projects in remote areas. Emerging digital technologies offer many advantages when leveraged by a D-MRV system. Forestry and land-use activities, for example, can be monitored using satellite data, which can be combined with AI and machine learning to better track project performance. Finally, D-MRV systems can simplify the verification of mitigation actions, as the verifying party can remotely access the system and confirm the reported information, relying on D-MRV system-defined algorithms to ascertain data quality, thereby reducing the frequency of on-site inspections, or removing the need completely for applicable project types.

5 Asian Development Bank. 2021. Digital Technologies for Climate Action, Disaster Resilience, and Environmental Sustainability. [Online]. Available: https://www.adb.org/publications/digital-technologies-climate-change [Accessed April 28, 2022].

**TABLE 2:** COMPARISON OF CONVENTIONAL AND DIGITAL MRVs FOR GHG EMISSIONS

| | CONVENTIONAL MRV | D-MRV |
|---|---|---|
| **Monitoring** | Manual recording of data from different entities within defined boundaries.<br><br>Entities monitor fuel consumption/production or electricity consumption/production through paper receipts, Excel files, or other manual systems.<br><br>Processes typically involve multiple people, are prone to human error, and are time-consuming. | Near real-time digital monitoring of electricity and fossil fuel consumption/production through smart meters, linked billing systems, and equipment sensors.<br><br>The resources dedicated to data collection can be reduced and redirected to QA/QC, reducing the time, travel expenses, and effort required to operate the MRV system.<br><br>Notifications/alerts could be built into the system to avoid data gaps or issues developing due to on-site disruptions. |
| **Reporting** | Recorded data is analyzed and compiled into a GHG emissions report. This is labor intensive, may require personnel to follow up on incomplete or incorrect reporting, and requires supervisory review of the report. | Digital MRV systems can generate automatic reports on GHG emissions using predefined templates.<br><br>Emissions data from an automated or manual monitoring process can be seamlessly analyzed, formatted, and reported.<br><br>The system can flag errors or be programmed to highlight large deviations in reported values relative to historic reports or similar activities in the same year. |
| **Verification** | Step-by-step audit of GHG report to ensure procedures are followed and no human error occurred. Facilitated through manual review of paper or electronic records supporting the MRV report. Hardcopy documents are easily lost or damaged over time, making review costly and time-consuming. | Validation/certification can be undertaken once at the digital MRV system level to ensure the workflow follows the GHG emissions reporting standards. Then GHG emission reports can be verified remotely through dedicated verifier user profiles, making the verification process faster and cheaper. A degree of automation in QA/QC could be achieved through screening of data based on predefined rules. |

**TABLE 3:** COMPARISON OF CONVENTIONAL AND DIGITAL MRVs FOR MITIGATION ACTIONS

| | CONVENTIONAL MRV | D-MRV |
|---|---|---|
| **Monitoring** | Manual collection of project data. This could be paper receipts or end-user data collected on a sampling basis for decentralized or household technologies.<br><br>Collecting technology performance/ user data is resource intensive and often involves travel to remote locations. | For most mitigation action projects, a digital MRV can collect project performance data in real time. For power projects this can be done using smart meters. Other activities can use remote sensors, satellite data, smartphone applications, and other tools to collect, upload, and analyze data on project performance. |
| **Reporting** | A monitoring report is prepared in line with the project's methodology, illustrating the steps to determine the measured sustainability benefit of the mitigation action. This usually requires a dedicated methodology or monitoring expert to gather evidence and project data from activity implementers. | Digital MRV systems generate automatic reports based on the mitigation action's methodology. The monitoring data is automatically analyzed, formatted, and reported.<br><br>Depending on the type of data, triangulation techniques can be built into the system to flag errors or outliers and quickly detect a hardware problem, such as a faulty sensor. For example, the electrical output of dispersed rooftop solar installations can be cross-checked against weather data on solar irradiance in the area to make sure the output is within an expected range. |
| **Verification** | Step-by-step audit of monitoring report, with manual review of paper or electronic records supporting the report.<br><br>Field visits are often required to verify evidence or samples taken during monitoring. | Verification can be undertaken once at the digital MRV system level to ensure the workflow follows the applied methodology.<br><br>Mitigation action monitoring reports from certified systems can be verified faster and at less cost.<br><br>Verification tools can be built into digitized MRV systems through dedicated verifier user profiles. Verification process can be further improved through D-MRV system flagging the monitored data according to predefined rules. |

# 3 Barriers to D-MRV systems

Barriers to the design, development, and effective implementation of D-MRV systems include a lack of technical expertise when designing and implementing the digital solution; a lack of availability of relevant technologies in certain jurisdictions; the need to put in place security measures to protect operational data; and lack of familiarity with the emerging technologies used by D-MRV systems.

A lack of technical expertise can affect every stage of the development process, from identifying appropriate technologies and designing the hardware and software solutions to calibrating smart sensors, maintaining distributed ledgers when using blockchain encryption, and tweaking machine learning algorithms. Relevant digital technologies are also generally more expensive and are not available in every country.

Using D-MRV systems exposes operators to potential data privacy risks because of the need to store large amounts of operational data—which could include information on private citizens—in a digital format. Sufficient measures to protect this data need to be put in place and maintained.

The methodologies used to determine emission reductions from different types of mitigation actions, as well as carbon standard-level validation and verification rules, predate emerging digital technologies. This presents a challenge as standard-setters may need real-world experience of running such systems before allowing them into their carbon project cycle.

Significant investments of both time and money are needed to overcome these obstacles to achieve all the functions that separate D-MRV systems from conventional MRVs.

# 4 Benefits of transitioning to D-MRV

D-MRV systems offer improved monitoring, reporting, and verification performance relative to conventional MRVs for both GHG emissions and mitigation actions.

## Easier, more reliable monitoring

Data monitoring is where the greatest chance of incorrect or incomplete data recording occurs. Conventional MRV systems still use hard copies of raw data from various meters, which are manually inputted to electronic worksheets. Hardcopy data is easily lost, damaged, or destroyed, and the inputting process is time-consuming and prone to error.

D-MRV systems can significantly increase the accuracy of recorded data by using digital technologies to collect, process, and store data. This reduces the potential for human error and lowers the risk of data loss.

To transition to digital monitoring, systems need to be put in place to automatically record data on site, at the required interval, and to digitally transfer the information to a database. Multiple technology solutions can be used to acquire and record this data, depending on the type of MRV:

- **Electronic billing systems** can automatically report on the consumption of electricity derived from fossil fuels, provided these purchases are logged on the unit. Renewable energy supplied to the grid can similarly be tracked. This technology is used in combination with IoT technologies (such as smart sensors) in many pay-as-you-go business models for solar home or biogas systems.
- **Smart sensors** can be programmed to capture and report on monitored variables—such as flow rates, electricity, and heat generation—at regular intervals. Many countries that are scaling up rural electrification use smart meters to enable users to buy electricity through their mobile phones.
- **Satellites and drone data** are already being used to analyze forest cover and other land-use projects. In combination with AI and machine learning, the D-MRV can be a powerful tool to quickly analyze large, remote areas.

These are a few examples of how new technologies that are becoming cheaper and easier to implement can be used to streamline monitoring for GHG and mitigation action MRV systems. The case studies in Section 2 provide examples of how these technologies are being used. In Uganda, grid-connected residents use their mobile phones to purchase prepaid electricity via their smart meters. In India, the Ministry of Power has committed to replacing existing meters with smart meters across the country by 2025.[6]

## Automated reporting

D-MRV systems can be set up to automatically analyze, process, and report on monitored data in custom formats. Unit conversions, calculations, and statistical analyses required by the methodology that underlies a GHG or mitigation action MRV can be programmed into the system, eliminating the chance of human error. Further QA/QC can be built into the system, such as noting large deviations in reported parameters during the monitored period or relative to previous reporting periods.

Standardized reporting formats are built into D-MRV systems so the monitored results, outliers, or flagged errors are clearly presented. D-MRV systems can also allow for seamless integration of the monitored and processed data, with narrative descriptions and comments by relevant stakeholders providing valuable detail on the project status or explaining potential issues with the data that the system might detect.

[6] Smart Energy. 2021. India's Smart Meter Rollout Timeline Released. [Online]. Available: https://www.smart-energy.com/industry-sectors/smart-meters/indias-smart-meter-rollout-timeline-released/ [Accessed: April 28, 2022].

## Streamlined verification

Verification can be the most expensive and time-consuming aspect of MRV systems. Verifiers often need to sift through large volumes of hardcopy data to validate a sample of monitored information. Digital technologies can streamline the verification process in three ways: by allowing for remote verification, by allowing initial system-wide validation with remote verification, and by improving accuracy and quality of data. All three of these methods reduce the cost and time required to verify GHG inventories and mitigation actions.

### Remote verification

With remote verification, a third-party verifier can log in to the D-MRV system via the internet without traveling to an on-site location in order to gain access to a complete set of relevant quantitative data (such as on-site measurements), as well as qualitative data (such as geotagged photos of project sites). In fact, the system they connect to does not need to be co-located with the project. This approach can reduce the frequency and length of site visits, especially for remote areas that are difficult to reach.

### Initial system-wide validation and remote verification

D-MRV facilitates a move towards one-time certification/validation of the entire D-MRV system. Once certified, the system is then able to remotely monitor data, while robust system checks ensure the confidence and credibility of the GHG impacts claimed. Appropriate data flagging allows verifiers to only investigate flagged data points.

### Improved accuracy and quality of data

Real-time data collection from all systems under a GHG or mitigation action MRV reduces the need for default parameters or sampling, and increases the accuracy of reporting. Mitigation outcomes that are verified using a robust D-MRV system could command higher market value than comparable outcomes using conventional MRV systems.

# 5 Resources needed to transition from MRV to D-MRV

Table 4 summarizes the differences between conventional and digital MRV systems at each stage of the MRV process to illustrate the additional resources needed to transition between these two types of MRV systems. Along with the checklist provided after, this table can be used to assess an existing MRV system and determine which processes or functionalities meet the conditions of a D-MRV system and which can be improved.

### TABLE 4: SUMMARY OF DIFFERENCES BETWEEN D-MRV AND MRV AT VARIOUS PROCESS STAGES

| MRV PROCESS | CONVENTIONAL MRV | D-MRV | RESOURCES NEEDED |
|---|---|---|---|
| **Collection of MRV data** | Data is recorded in hard copies (forms or report templates) that are manually collected on a recurring basis | Data is automatically, digitally recorded using smart sensors or satellite images at intervals or in real time | Smart sensors and software are necessary for collection and transfer of information |
| **Transfer and storage of MRV data** | Hardcopy data is stored as is or manually transferred to an electronic format (such as a worksheet) | Data is digitally transferred to a secure on-site or cloud server for storage and backup. The data can be "hashed" (converted from plain text into cipher text) to a blockchain or recorded in cloud-based, immutable storage (for traditional ledgers) to ensure it hasn't been tampered with | Digital transfer, storage, security, and backup of data |
| **Analysis and reporting** | Analysis and reporting are manual and prone to human error | Algorithms for data conversion and analysis have been programmed into the system, enabling a repeatable process. Reports are produced in different formats | Data digitalization and computer code for analysis and reporting |
| **Quality assurance/ quality control** | Any QA/QC requires manual, expert review of hardcopy data or electronic worksheets | Detection of outliers or missing data can be pre-programmed and is done continuously to detect faulty sensors or other outliers | A reporting system with algorithms that send notifications when faulty data has been collected and needs to be addressed |
| **Third-party review and verification** | Recurring sampling and manual review of hardcopy data, often requiring on-site inspection | Remote access to monitored data. Automatic verification of data by comparing data with a control copy (or blockchain/ cryptographic hash) | Dataset control source (backup repository, immutable cloud storage, cryptographic proof or blockchain) accessible via the internet |

## Converting a conventional MRV to a D-MRV system

To further illustrate how to move from a conventional to a D-MRV system, Table 5 below provides a checklist for key D-MRV functionalities across monitoring, reporting, and verification processes. Ideally, all the technical functionalities listed should be met to realize the benefits of a D-MRV system.

D-MRV systems can be partially digitalized. For example, data collection, transfer, and reporting could be digital without remote access or securing of collected data. The case study on the EDIMS MRV in Uganda is an example of a partially digitalized MRV that sees electricity consumption digitally recorded and reported through smart meters. The EDIMS is also able to calculate emission reductions resulting from this data; however, digital technologies are not being used to ensure data integrity or for remote data validation or verification.

### TABLE 5: D-MRV CHECKLIST

| STAGE | REQUIRED TECHNICAL FUNCTIONALITY | TICK FOR "YES" |
|---|---|---|
| **1. Monitoring** Data collection and storage technologies | Digital measurement of monitored parameter | ☐ |
| | Secure transfer of data to digital storage location | ☐ |
| | Storage of data on an accessible device | ☐ |
| | Immutability of collected data | ☐ |
| | Automatic backup of monitored data | ☐ |
| | Conversion or transformation of data formats into a standard format for analysis | ☐ |
| **2. Reporting** Data processing and analytics technologies | Data analytics that comply with the methodology and provide repeatable results have been programmed into the system | ☐ |
| | Generation and sharing of monitoring reports | ☐ |
| | Automated QA/QC to detect data outliers or sensor malfunction | ☐ |
| **3. Verification** Data processing and analytics technologies | Remote access to monitored data and automated verification through rule-based data flagging (for example, automated QA/QC) | ☐ |
| | Ability to compare data against the backup raw monitored data | ☐ |

# 6 Elements of an enabling environment for D-MRV systems

Moving towards widespread use of D-MRV systems, and realizing the benefits of these systems, will require overcoming multiple barriers. An enabling environment for emerging digital technologies—and the systems using them—will facilitate overcoming these barriers.

For project entities to adopt digital technologies for MRV systems, it is crucial to have a clear picture on domestic policy requirements (or support to adopt them); understand the benefits of adopting such systems (mainly to reduce transaction costs and minimize operating and maintenance costs); and fully understand the roles and responsibilities associated with better data management.

An enabling environment seeks to provide the policies, institutions, regulations, and infrastructure conducive to the desired outcome, in this case the widespread use of D-MRV systems. There are four key aspects to an enabling environment:

- A conducive domestic and legal environment
- A conducive institutional environment
- An enabling private sector and NGOs
- Social dialogue and public participation.

## The domestic and legal environment

To promote the implementation and use of D-MRV systems, governments need to ensure that regulations, policies, and guidance on how sensitive data is collected, secured, stored, and used are in place. While both conventional MRV and D-MRV systems may contain confidential information on businesses, private citizens, or other stakeholders, the digital format of information in a D-MRV system could increase the risk that the data could be accessed and distributed by unauthorized users.

The importance of data-management controls depends on the sector or type of mitigation activity being monitored. Some MRV systems contain customer contact information, while others work only with weather data or satellite images that may already be publicly available. Guidelines on the privacy or security of sensitive information should be provided, and the D-MRV system operator should inform individuals providing data to the system about how their data may or may not be treated and used. If the data provider is a private person, they should be given the option to provide consent for their personal information to be used.

Countries should explore how they can use technologies that are already in place for other services for D-MRV, or how they can use D-MRV to promote or foster technologies for purposes that the country has a strategic interest in. In the power sector, for example, digital monitoring and reporting of electricity generation and consumption is often already standard practice, with relevant guidelines and policies in place. These existing D-MRV systems and guidelines can be leveraged both to track emissions or mitigation outcomes from the power sector, and to inform the development of D-MRV policies for other sectors.

Where guidelines or policies for D-MRV systems still need to be developed, the following should be considered:

- **The reporting requirements** issued by the government with respect to a particular carbon pricing initiative or international agreements such as the Paris Agreement
- **Minimum security standards for data**, for example, encryption and backup requirements, how data should be secured, and which users have access
- **How consumer or end-user data should be collected**, terms-of-use agreements, how long data may be stored, user consent processes, and anonymizing data
- **What type of personal data is eligible for aggregation** under the system.

As an example, Turkey adopted regulations for MRV systems when the country developed a data-management system to comply with the reporting requirements of the Paris Agreement. In the lessons learned report, understanding the stipulations of the regulation on MRV systems was the first step taken towards developing the data-management system, as the regulation underpins what data the system can collect and how the data is managed.[7] This highlights the importance of policy or regulations around MRV systems and data collection to facilitate the use of D-MRV systems by both governmental and non-governmental organizations in a country.

## The institutional environment

In addition to national regulations, policies around data collection, storage, and use need to be in place. An organization managing a D-MRV system, or accessing data from one, should have internal guidance or protocols in place specific to the type of data it is handling. D-MRV systems for reforestation or afforestation activities, for example, may monitor land ownership by individuals to track the number of trees on the property. This would require different data-protection protocols to a D-MRV that tracks power production at large-scale renewable energy facilities.

Regulatory bodies and international standards that have protocols and rules to assess compliance need to update these standards and protocols to allow for use of D-MRV systems. For example, the international standards that certify carbon credits, such as the Verified Carbon Standard (VCS), the Gold Standard, the CDM, and the Article 6.4 mechanism, will need to revise their monitoring methodologies and verification protocols to allow for the use of digitally monitored and reported project data, as already initiated by the Gold Standard in its clean cooking monitoring methodology. The European Bank for Reconstruction and Development (EBRD), with support from the Spanish Office of Climate Change and inputs from the Joint Multilateral Development Banks (MDB) Working Group on Article 6, commissioned a protocol for D-MRV systems using renewable energy generation projects as an example. The protocol provides a blueprint for data collection, automating data processing and reporting, remote verification, and system-wide certification of projects using D-MRV systems. The case study supporting this paper, titled *EBRD D-MRV System for Renewable Energy*, shows the application of the EBRD's protocol.

[7] Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). 2017. MRV in Practice: Experience in Turkey with Designing and Implementing a System for Monitoring, Reporting and Verification of GHG Emissions. [Online]. Available: https://www.giz.de/en/downloads/MRV_in_Practice_Booklet_2017.pdf [Accessed April 28, 2022].

Beyond data privacy and security issues, organizations may need to adjust policies and procedures to shift from paper-based to digital processes. Monitoring protocols need to be revised to allow digital data in place of self-reported, manually collected data. The use of digitally collected data requires the development of repositories designed to capture information in the data format from the relevant system. Guidelines need to be developed on how to handle outlier or false data, and instructions on usage and interpretation of monitored data should be available. The international standards and regulatory bodies should reassess their reliance on PDF-style reports or provide options for automating the production of these reports, while moving towards dashboard-like systems that can be remotely accessed.

In addition to revising monitoring and reporting protocols, validation and verification rules need to be updated or revised. One of the main anticipated benefits of D-MRV systems is cheaper and faster verification of mitigation actions without detracting from accuracy or environmental integrity. This can be achieved by initially validating the monitoring system, after which system reviews can be limited to data anomalies. Verification can be supported by remote access to monitored data and eventually become continuous. Verifiers will need to be able to ensure that reporting results are repeatable and prove the integrity of datasets.

Successfully moving towards this type of system-wide certification and remote, automated verification will streamline the generation of carbon credits, potentially allowing for near real-time issuance as the underlying project(s) are monitored. Periodic audits of the D-MRV system may still be required, but overall using system-wide certification in place of recurring, labor-intensive verification processes will greatly reduce the time and cost of monitoring, and real-time generation of carbon credit assets will improve the liquidity of carbon markets.

To support the implementation of the changes described, mechanisms should be in place for institutions, standards, regulators, and verifiers who are working with D-MRV systems (or are planning to), to share their experiences with one another. Examples of such mechanisms include the Joint MDB Working Group on Article 6[8] and the Gold Standard's D-MRV collaboration work.[9]

## An enabling private sector and NGOs

For D-MRV systems to support mitigation actions, digital technologies and skills need to be both available and affordable. Widespread internet access and the presence of cellphone towers, especially in rural areas, can facilitate near real-time data collection from technologies like smart meters and digital sensors. Tax exemptions can also be applied to drones, smart meters, digital sensors, and other technologies that make up D-MRV infrastructure to reduce the overall systems cost.

Verifiers of mitigation actions need to familiarize themselves with D-MRV systems so that they can implement revised protocols from regulatory bodies and international standards. This includes validating systems using blockchain for unique identification in place of hardcopy records, or employing AI programs that use historical data to predict project performance. Capacity in implementing organizations and third-party verifiers can be developed by hosting information and training sessions on D-MRV systems, by demonstrating how to harness the integration of emerging technologies into these systems, and by engaging auditors to directly review and mock-certify pilot D-MRV systems.

Sylvera, a company that provides independent ratings for carbon credits from nature-based solutions, uses D-MRV systems and AI to develop models to assess different performance criteria, such as above-ground biomass and changes in forest cover across project areas. The company then assigns a rating to the project so that carbon credit

[8] World Bank Group. 2018. MDB Working Group on Article 6 of the Paris Agreement. [Online]. Available: https://www.worldbank.org/en/topic/climatechange/brief/mdb-working-group-on-article-6-of-the-paris-agreement [Accessed April 28, 2022].

[9] Gold Standard Foundation. 2021. Open Collaboration on Next Generation Digital Solutions for MRV. [Online]. Available: https://www.goldstandard.org/blog-item/open-collaboration-next-generation-digital-solutions-mrv [Accessed February 18, 2022].

buyers can assess the quality of those projects. Sylvera raised $32 million in private capital, demonstrating the need for assessments of the quality of different types of carbon credits.[10] Sylvera plans to expand beyond nature-based solutions and provide ratings for all types of carbon credit projects. The company's service and underlying D-MRV systems are one of the case studies shown in Section 2.

## Social dialogue and public participation

Making D-MRV data publicly available has many benefits. For example, some D-MRV systems have the potential to aggregate large amounts of information that can be useful beyond tracking GHG emissions or emission reductions from a mitigation action. Data can be publicized to promote the technology or measure being tracked, and projects that make their data available will benefit from crowdsourced QA/QC.

However, there is also the need to protect personal privacy and respect data ownership rights. Proper safeguards need to be put in place. For example, the rooftop solar home system case study in India, managed by the National Institute of Solar Energy (NISE) in India, tracked solar energy generated by rooftop solar systems. NISE considered making the generation data publicly available, but the solar technology vendors providing the data objected as these companies were charging consumers a subscription fee to view their generation data.

## Taking a multifaceted approach to developing an enabling environment

Creating an enabling environment for D-MRV systems requires a multifaceted approach. National regulations on data collection, management, and use are needed so that systems operators understand the framework within which they can operate. A comprehensive and clear policy on digital technologies and data-management systems simplifies the implementation of complex D-MRV systems. Regulations—in combination with further government support for D-MRV systems through tax exemption of digital technologies, a robust telecommunications network, or promotion of internet connectivity in underserved regions—can help reduce the cost of transitioning to D-MRV. At the same time, international standards on emission reporting and emission-reduction certification need to update their protocols and guidelines so that implementers of D-MRV systems, which take on the increased complexity and cost of these systems, can also see the benefits.

A national framework for the creation of an enabling environment for D-MRV systems would be a valuable tool for countries seeking to meet the reporting requirements of the Paris Agreement, specifically Article 6. The development of this national framework would benefit greatly from capacity building and education of relevant stakeholders on D-MRV systems, the underlying technologies, and best practices. Lessons learned from piloting of digital technologies for GHG inventories or mitigation actions should be widely shared to avoid repetition of mistakes and ease the uptake of these technologies.

[10] Verdantix. 2022. Sylvera Fund Raising of $32 Million Will Enhance the Integrity of Nature-Based Carbon Credits. [Online]. Available: https://www.verdantix.com/blog/sylvera-fund-raising-of-32-million-will-enhance-the-integrity-of-nature-based-carbon-credits [Accessed April 28, 2022].

An example of a framework for D-MRV systems is a paper by Microsoft and the InterWork Alliance titled *Digital MRV Framework: Digital Measurement, Reporting & Verification Framework*.[11] This white paper suggests terminology and processes that should underpin any D-MRV system so that there is a common understanding and foundation from which to build D-MRV systems and the required enabling environment.

One of the main criticisms of the carbon credit generation governed by independent standards—whether for compliance purposes under the CDM or voluntary markets, as with the Gold Standard and VCS—is the time and cost of monitoring and verifying projects. As discussed earlier, D-MRV systems could significantly reduce these barriers, while maintaining the rigorous accuracy and quality requirements of certification standards for post-2020 carbon markets.

The independent standards have accumulated extensive experience on suitable guidelines for development of mitigation actions and monitoring of those activities. This experience is reflected in the library of monitoring methodologies and project standards/protocols governing project development, validation, monitoring, verification, and issuance. These documents are regularly updated to streamline usability. As discussed in the section on an enabling environment, to promote the use of D-MRV systems, monitoring methodologies and project standards need to be adapted to reflect digital technologies and processes.

Two case studies included in this report have already taken steps to adapt available monitoring methodologies for D-MRV systems. The case study on EDIMS in Uganda explains how a CDM methodology on rural electrification activities was revised to allow for monitoring data to be reported by prepaid smart meters. This was a deviation from conventional electricity meters, which record power usage after the fact, since the prepaid meters report on electricity purchased before consumption, on the assumption that users would consume the electricity they purchased. The D-MRV system covering waste in Chile also adapted an existing monitoring methodology to accommodate digital technologies, and is aiming for system-wide verification.

[11] Microsoft Corporation. 2021. Digital MRV Framework: Digital Measurement, Reporting & Verification Framework. [Online]. Available: https://interwork.org/wp-content/uploads/2021/11/Digital-MRV-Framework-1.0.pdf [Accessed April 28, 2022].

# 7 A parameter assessment tool for methodologies under D-MRV systems

Methodologies will need to be revised to accommodate AI, smart meters, remote sensors, and satellite or drone images. The Gold Standard is expanding its project cycle to include use of D-MRV and in July 2021 revised its cookstove methodology to allow for "direct measurement and remote monitoring methods".[12] To further support this process, this chapter includes an assessment tool to determine if a parameter, as defined in each methodology, can be incorporated in a D-MRV system.

To facilitate the transition to D-MRV systems, a high-level tool was developed to assess if a parameter can be monitored and reported under a D-MRV system. The tool consists of a decision tree that aims to establish if a parameter should be tracked using digital technologies, given that the use of these systems and technologies can be costly. The tool considers the following questions, which are not necessarily sequential and could be asked in a different order:

- **Is the monitoring, reporting, and verification of the parameter costly or time-consuming?**
  The decision tree begins by assessing the cost and effort to monitor the parameter in question. If the cost and/or effort is relatively low, then a D-MRV system is probably not necessary. An example of such a parameter is the lifetime of a technology or product, which is easily identified by technical specifications, contracts, or warranties, and is constant for the life of the technology.

- **Can the parameter be substituted with an approved default value?**
  If the parameter is expensive or time-consuming to monitor, a default value may be provided in the monitoring methodology. If this value is representative of the conditions of the project, it can be applied and a D-MRV system is not needed. Default values are provided for project parameters such as wood savings from efficient cookstoves and emission reductions from solar lamp usage.

- **Are digital technologies available to measure and record the parameter?**
  For parameters for which no usable default value is provided in the monitoring methodology, the next question is whether it is possible to use a D-MRV system to measure that parameter. The digital technologies and underlying systems that can monitor the parameter need to be identified. It is possible that some parameters cannot be measured under D-MRV systems. An example of this is the average household size in a project boundary or country. This information may be available from studies, but cannot easily be measured by a D-MRV system.

- **Is the use of these technologies for this purpose allowed by governing laws or regulations?**
  If a suitable digital technology is identified to measure and record the parameter in question, any applicable laws and/or regulations should be reviewed to ensure that using the identified technologies to collect the desired data is permitted.

[12] The Gold Standard Foundation. 2021. Reduced Emissions from Cooking and Heating Version 4.0. p 31. [Online]. Available: https://globalgoals.goldstandard.org/standards/407_V4.0_EE_ICS_Reduced-Emissions-from-Cooking-and-Heating-TPDDTEC.pdf [Accessed April 28, 2022].

- **Is the mitigation activity using a D-MRV system for other parameters?**

  If steps 1-4 are satisfied—meaning that it is worthwhile to monitor the parameter digitally, no suitable default value is available, digital technologies are available to monitor the parameter, and the identified technologies are legally permitted—the next step is to identify if a D-MRV system is already in place for the mitigation activity for a different purpose (for example, a supervisory control and data acquisition system in a power grid). If so, the monitoring of the new parameter might be possible using the existing system. Otherwise, a D-MRV can be built from scratch.

- **If yes, then can the monitoring and reporting of the parameter be incorporated into the existing system?**

  If a D-MRV system is already in place, determine if monitoring of the new parameter, and any new digital technologies, can be built into the existing system.

- **If no, is developing a D-MRV for the parameter cost prohibitive?**

  If no D-MRV system is in place, evaluate the cost of developing the system.

- **Does the digital monitoring of the parameter require a modification in the project technology or activity?**

  The next step is to determine if the technology or service implemented under the mitigation activity requires modification to accommodate monitoring and reporting under a digital system. An example of this is installing digital heat sensors on efficient cookstoves to track usage and operating temperature.

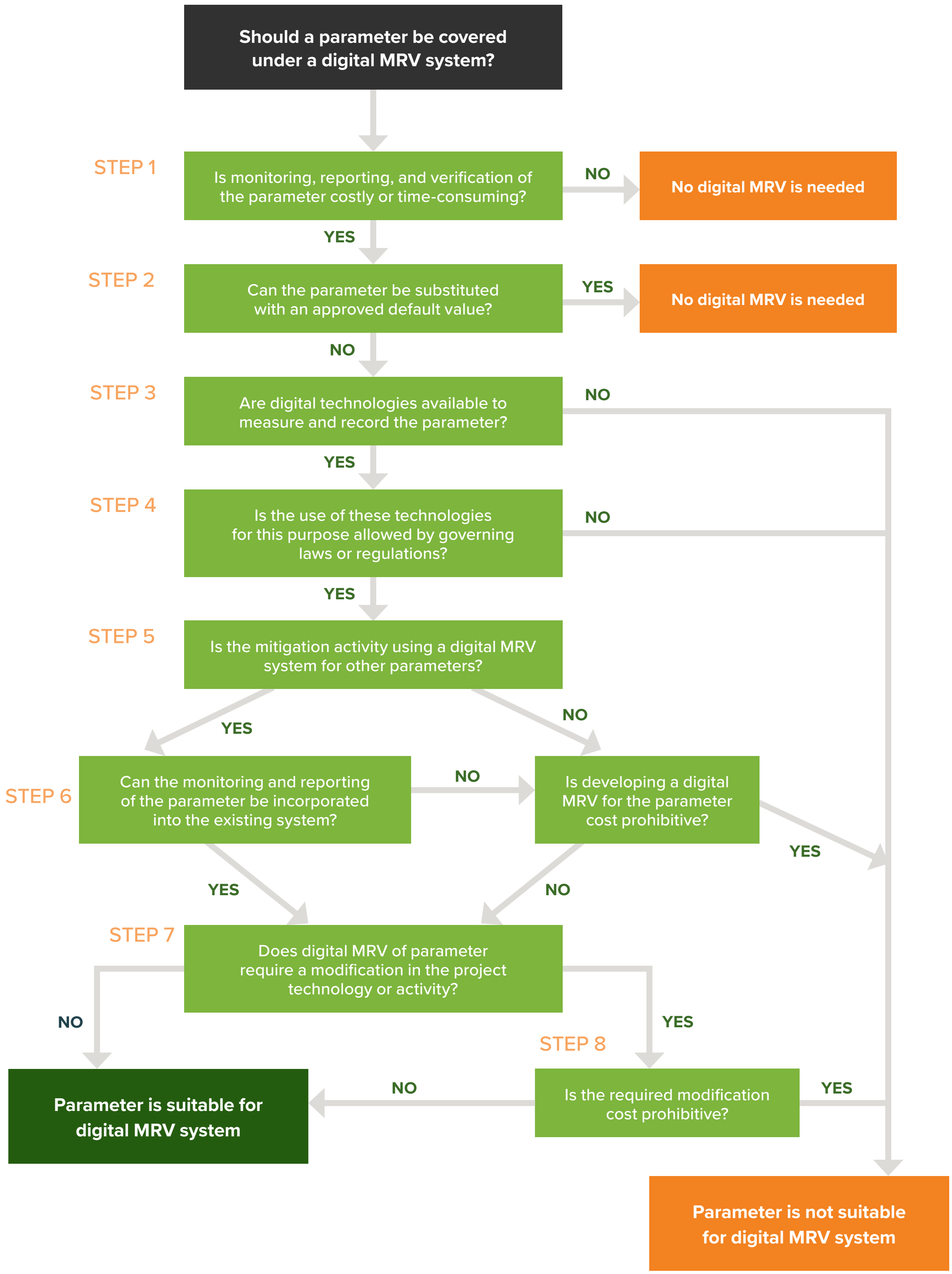
- **If no modification is required**, and the above steps have been followed, the parameter is suitable for a D-MRV system.

- **If modification is required**, determine if the cost of doing so is unviable, too costly, or difficult. If not, the parameter is suitable for a D-MRV system.

Figure 2 provides a general framework for assessing whether a parameter specified under a monitoring methodology is suitable for a D-MRV system. The affordability of digital technologies and the underlying system infrastructure is a key consideration when making the final decision. The D-MRV systems in the case studies all had external funding—usually from development banks or donors—to develop the D-MRV systems. Monitoring methodologies may also need to be updated to include the use of digital technologies for monitoring, reporting, and verification.

When applying this tool, it is important to view digitalization of an individual parameter in the context of the wider scope of MRV of a particular mitigation activity, since typically there are multiple parameters to be monitored. Even if a parameter is not suitable for a D-MRV system, there could still be a benefit to using a D-MRV for the overall project. For instance, default values could still be built into D-MRV, while the other parameters are digitally monitored and integrated into D-MRV to yield GHG results.

## FIGURE 2: DECISION TREE FOR ASSESSING IF A PARAMETER IS SUITABLE FOR A D-MRV SYSTEM



## Common mitigation activity parameters under D-MRV systems

Table 6 provides a summary of commonly monitored parameters for mitigation activities to help project developers assess if and how these parameters can be measured under a D-MRV system (see the Appendix for the full table including examples, monitoring frequency, reporting measures, possible remote verification methods, and parameters for which D-MRV systems are not necessary or beneficial).

Blockchain encryption technology can be applied alongside D-MRV systems, regardless of the digital technologies used to collect the project data, to ensure the integrity of the information. Blockchain technology and immutable data storage in the cloud can support post-2020 carbon markets to transition to one-time certification of D-MRV systems with recurring remote verification of project data.

### TABLE 6: COMMONLY MONITORED PARAMETERS AND CORRESPONDING DIGITAL TECHNOLOGIES

| PARAMETER | DESCRIPTION | MONITORING METHOD/S | DIGITAL TECHNOLOGY | QUALITY CONTROL |
|---|---|---|---|---|
| **EGgrid**[13] | Electricity generated during a time period by a gird or mini-grid connected plant | Electrical meters at interconnection points can measure power generation | Smart meters (or digital meters with data loggers) continuously record and report power generation | Power generation data recorded by smart meters can be uploaded to D-MRV and cross-checked against other independent variables (such as solar irradiance) |
| **Number of units** | Number of project systems or users under activity | Sales records, installation certificates, number of connected systems | Sales or installation data using smartphones or purchasing software, system monitoring software | Cross-checked with wholesale purchase or import data |
| **Carbon stock**[14] | Tonnes of carbon dioxide per volume or mass of biomass | Satellite data or in-person inspection of biomass | Use AI to analyze satellite or drone data to measure deforestation | Periodic in-person inspection to verify reports from satellite data and AI software |

[13] This parameter is monitored using a D-MRV system in the India rooftop solar and EBRD solar photovoltaic case studies.

[14] This parameter is monitored using a D-MRV system in the case study on forestry systems.

# 8 Conclusion and way forward

The transition to D-MRV systems, made possible by emerging technologies, will have the potential to become a core component of post-2020 carbon markets. Forestry and renewable energy projects are already relying on satellite data, AI, smart meters, and digital sensors to record and report emission reductions (or removals). Examples of these D-MRV systems already in pilot or implementation phases are shown in the case studies in Section 2.

In addition to cheaper and faster data collection, securing the information through blockchain technology or immutable cloud storage is important to facilitate the verification of emission reductions from mitigation activities. The Wood Tracking Protocol (WTP) project in Peru demonstrates how blockchain can be used to track a product through its development or supply chain. Beyond MRV systems, blockchain technology is also being considered to secure transaction registries to track the transfers of mitigation outcomes between participants under Article 6 of the Paris Agreement.[15]

While D-MRV systems and the underlying technologies have the potential to streamline carbon asset generation and reduce the cost of verifying emission reductions, there is an upfront cost and increased complexity that needs to be overcome. Once in place, though, it is likely that the cost of scaling or replicating a D-MRV system will be less than for a conventional MRV system. In addition, the potentially modular structure of D-MRV systems can reduce the cost to implementers of mitigation activities by providing access to digital reporting and verification systems at the sectoral or national level, and focusing their efforts on digitizing the monitoring of their activity.

Initial barriers to D-MRV systems can be more easily overcome with a strong enabling environment for digital technologies. The support of key stakeholders—whether governments, multinational organizations, or international standards—for D-MRV systems is a necessary first step. This includes the following components:

- Governments developing policies and frameworks for data collection, management, and use.
- Existing international voluntary standards adapting monitoring methodologies and standard-level requirements for validation and verification to allow, and accommodate, digital technologies and D-MRV systems.
- New country-level crediting frameworks and emerging international compliance mechanisms such as CORSIA (the Carbon Offsetting and Reduction Scheme for International Aviation) and Article 6.4 designing their protocols and methodologies with D-MRV systems in mind.
- Governments and multinational organizations providing financial support and technical expertise to overcome the initial barriers to implementing D-MRV systems, including through practical demonstrations of pilot systems.

[15] Climate Ledger Initiative. 2021. Navigating Blockchain and Climate Action. [Online]. Available: https://www.climateledger.org/resources/CLI-Navigating-Report-December-20213.pdf [Accessed April 28, 2022].

In addition to the enabling environment, further piloting of D-MRV systems and their functionalities in different regions for a range of project types will allow for further testing of emerging technologies and the development of a knowledge base to optimize, replicate, and scale D-MRV systems. In addition to the case studies highlighted in this paper, the World Bank's Climate Warehouse initiative is simulating the interconnection of D-MRV systems and carbon market registries to demonstrate how these systems can share information.

These lessons learned will have benefits across project types and regions. While the data used to train an AI to track forest growth in South America may not be applicable to Southeast Asia, the same machine-learning algorithm could be used with a different training dataset. Further, blockchain technology to secure the data of a D-MRV is mostly the same regardless of the technology used for data collection.

A strong enabling environment and concerted efforts to pilot a range of emerging technologies will support the widespread adoption of D-MRV systems. This could unlock carbon markets' full potential to combat climate change while setting the stage for future innovations such as the tokenization of carbon assets through blockchain technology and real-time issuance of mitigation outcomes from projects with system-wide certification of their D-MRV.

# Section 2: Case studies

**JORDAN**
European Bank for Reconstruction and Development D-MRV system for renewable energy
p48

**INDIA**
Grid-connected rooftop solar photovoltaic system
p29

Global Mangrove Trust's GROVE: Forestry Smart Ledger
p39

**PERU**
Wood Tracking Protocol D-MRV
p38

Third-party ratings of nature-based carbon credit projects
p43

**UGANDA**
Electronic database and information management system
p32

**CHILE**
Waste-to-energy landfill D-MRV
p25

Open Surface reforestation/ afforestation D-MRV
p37

**GABON**
Third-party ratings of nature-based carbon credit projects
p43

# 1 Chile waste-to-energy landfill D-MRV

## Type of system: Mitigation action

The Chile waste-to-energy D-MRV system was piloted at a landfill capture-and-destruction system at the Copiulemu landfill in Chile between January 2020 and March 2022. It was a project under the Reciclo Orgánicos Program, a partnership between the Canadian and Chilean governments to support the implementation of Chile's NDC under the Paris Agreement. The mitigation action did not pursue registration under an international carbon credit standard because the emission reductions will be counted towards the country's NDC.

The D-MRV system for tracking and reporting emission reductions at Copiulemu was built on top of the facility's newly commissioned, state-of-the-art measurement and management system. The D-MRV system tracked gas flow rates, gas composition, and combustion efficiency, among other metrics.

An online, multistakeholder process was followed to develop a landfill gas methodology for Chile based on several established methodologies and protocols. The D-MRV system itself was jointly developed by the IOTA Foundation and ClimateCHECK, a Canadian company that provides measurement, reporting, and verification for climate, cleantech, and sustainability solutions.

This first phase of the project covered testing of the monitoring and data systems, such as direct monitoring of system data, quality assurance, device connectivity, and information security. The main parameter tracked by the D-MRV system was the capture and burning of biogas, which was recorded at 15-minute intervals, covering about 100,000 unique data points per year.

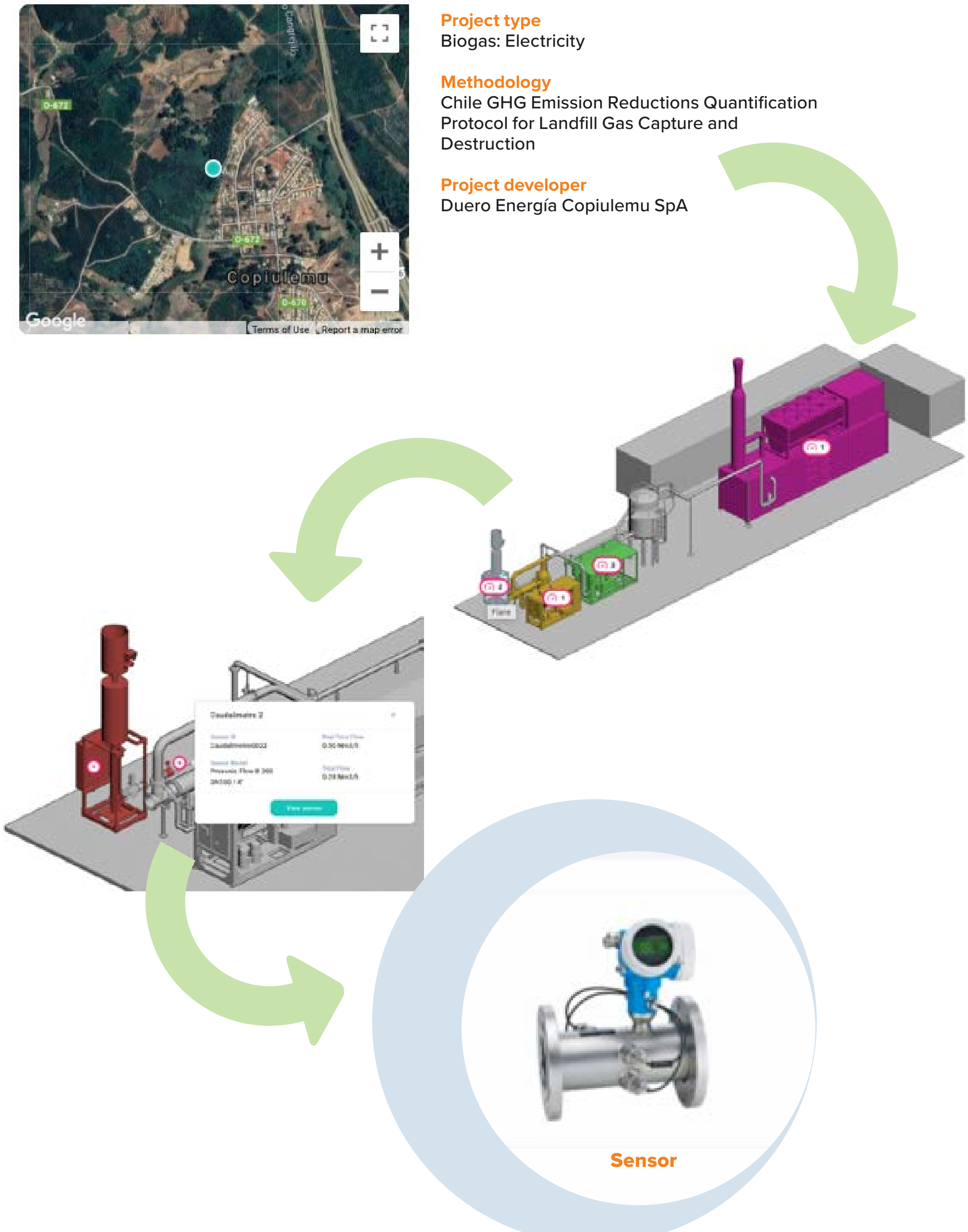
## Technical details

### The use of digital/IoT sensors

The D-MRV was supported by various digital technologies. On-site digital sensors recorded data related to the volume and composition of biogas produced at the landfill, in accordance with the MRV methodology. The volume of biogas was recorded in cubic meters and monitored every 15 minutes. By measuring the composition of the gas, it was possible to record the percentage of methane in the biogas. The destruction of methane resulted in the project's emission reductions due to the high global warming factor of the methane gas (approximately 25 times that of carbon dioxide).

The digital sensors recording gas flow and composition reported the data to a dedicated server at the landfill, from where it was uploaded to the cloud. A dedicated on-site computer was used for the D-MRV system to avoid the complexity (including security and compatibility issues) of installing the D-MRV software on the landfill operator's computer system. Monitoring and data records that acted as supporting evidence—for example, photos of sensors and equipment, calibration records, sensor manuals, and monitoring plans—were incorporated into the D-MRV system. A 3D digital twin of the project site and sensors was incorporated into the portal's user interface to enable a virtual audit user experience. The D-MRV portal was integrated with ScribeHub, an online document collaboration platform, to enable customizable online project reporting and verification reporting according to the MRV methodology and international standards.

## FIGURE 3: DIAGRAM OF CHILE'S WASTE-TO-ENERGY D-MRV SYSTEM



## Information security through distributed ledger technology

An innovative component of the D-MRV system was the use of distributed ledger technology (DLT, popularly known as blockchain) to secure data collected by the system. The D-MRV used IOTA's permissionless DLT, which uses a directed acyclic graph rather than a traditional blockchain. This means that data is not stored in a single chain and can have multiple branches, enabling transactions to take place simultaneously. Unlike blockchains, IOTA's DLT enables energy-efficient performance and high transaction throughput with no fees for transferring data. IOTA's technology can also be used for data marketplaces (MRV data can be used for multiple purposes) and for the tokenization of carbon credits generated by the mitigation action underlying the D-MRV system.

## Adaptation of landfill gas MRV methodology

To ensure that the D-MRV system could support the MRV of emission-reduction certification from the underlying mitigation action, ClimateCHECK managed an online, multistakeholder process to develop a custom MRV methodology that was adapted from:

- The Quebec Ministry of Environment's Cap and Trade Protocol: Landfill Sites—CH4 Treatment or Destruction
- Offset Initiative Protocols for Ontario's Cap and Trade Program: Landfill Initiative Protocol
- Climate Action Reserve's United States Landfill Protocol.

Most internationally recognized MRV methodologies were developed without specific consideration of digital technologies. As a result, projects cannot access the full benefits of digital technologies without customizing the MRV methodology. The customized Chile Landfill Gas protocol allowed for quantification of emission reductions using the data collected by the on-site digital sensors, as well as remote verification due to the security and integrity of data offered by IOTA's DLT technology.

## Full-cycle digital MRV

This D-MRV system was unique as it was designed to cover the full MRV process, from developing the MRV methodology to the verification of emission reductions. Figure 4 shows the different components of the D-MRV system. The project site covers all hardware involved in the D-MRV, including digital sensors and the on-site computer.

The figure illustrates how monitoring was conducted on site and how the collected data was secured using the IOTA DLT technology and stored in the D-MRV portal. The other main component of the D-MRV system was the online verification reporting through ScribeHub, which streamlined processes that are expensive and time-consuming in conventional MRV systems.

# Lessons learned and continued use of digital technologies

## The use of DLT

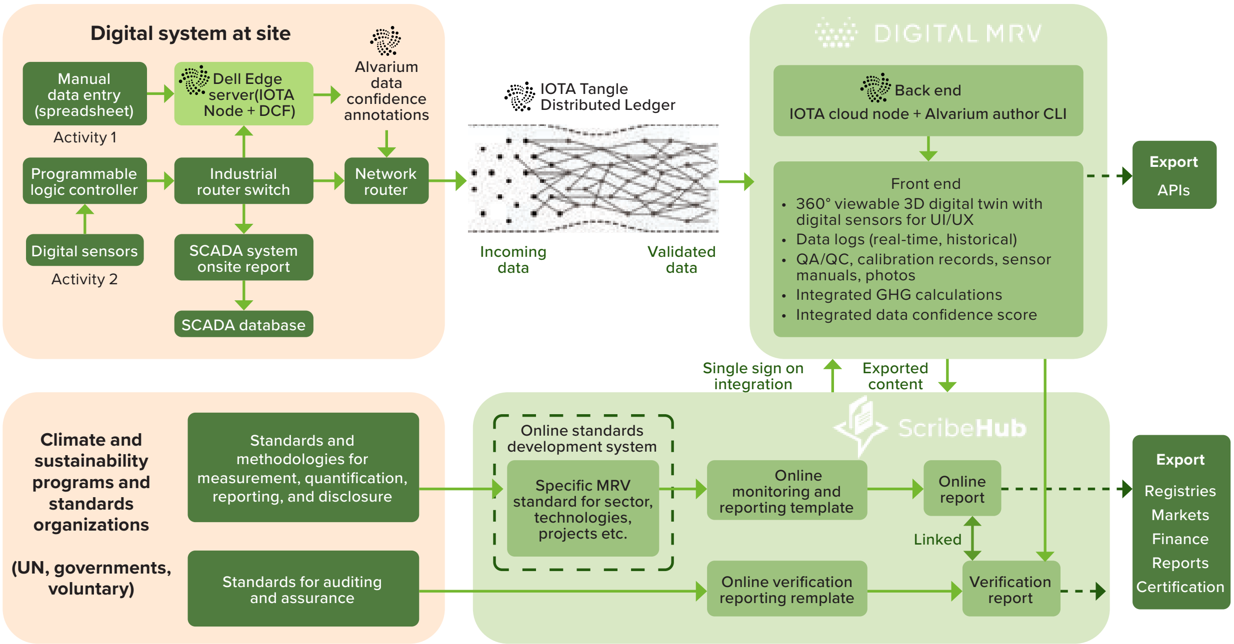
While Chile's waste-to-energy D-MRV system has only recently completed its pilot stage, some notable lessons were learned.

At the conceptualization stage, there was concern that the DLT would increase the complexity of the D-MRV system. In practice, the implementation of the DLT was simpler than expected as IOTA's DLT is specifically designed for these types of D-MRV systems. The Chilean government also had little difficulty in endorsing IOTA's DLT and understanding how the DLT encryption ensures the integrity of collected data for the purpose of validation and verification.

## Productization of D-MRV system

The pilot phase was implemented at a single landfill. As a next step, under the Reciclo Orgánicos Program, the system will be expanded to cover other landfills with methane capture-and-destruction measures. The system will aggregate emission reductions across Chile's waste sector and transparently report the sector's contribution to Chile's NDC. Eventually, the D-MRV system can be modified to suit other types of mitigation actions.

## FIGURE 4: COMPONENTS AND STRUCTURE OF THE CHILE WASTE-TO-ENERGY LANDFILL D-MRV SYSTEM[16]




In addition to expanding the geographic and sectoral scope of the D-MRV system, further functionalities can be incorporated. From the IT side, future improvements of the D-MRV system include using digital solutions to:

- Report data from the digital MRV system directly to a national GHG inventory
- Verify emission reductions in real time as data is collected
- Link to carbon credit registries and/or market-places.

Systems such as the Chile waste-to-energy D-MRV are an important part of cost-effective and transparent reporting of GHG emission reductions in sectors that fall under a country's NDC and have industrial processes where smart sensors can record data in real time. The innovative use of DLT to ensure the integrity of data collected is equally important for the integrity of future carbon credit markets.

[16] Dell Technologies. No date. Project Alvarium Accurately Tracks Carbon Footprints with Edge Solutions. [Online]. Available: https://www.dell.com/en-us/dt/video-collateral/project-alvarium-tracks-carbon-footprint-with-edge-solutions.htm [Accessed June 14, 2022].

# 2 Grid-connected rooftop solar photovoltaic system in India

## Type of system: GHG emissions

The government of India, in partnership with state governments and electricity regulators, adopted and implemented policies and programs promoting the deployment of grid-connected rooftop photovoltaic (GRPV) systems. To determine the success of these programs, an MRV system to collect data on the performance of these systems was needed. The data would populate a vast database that would:

- Allow project developers and financiers to moni-tor project performance and identify systemic inefficiencies
- Enable electricity distribution companies (locally known as DISCOMs) to plan for supply requirements
- Generate market data on the performance of various rooftop systems
- Potentially support the generation of mitigation outcomes for India's NDCs.[17]

The expected use of data by various stakeholders had implications for the type of data collected and how the data was to be managed.

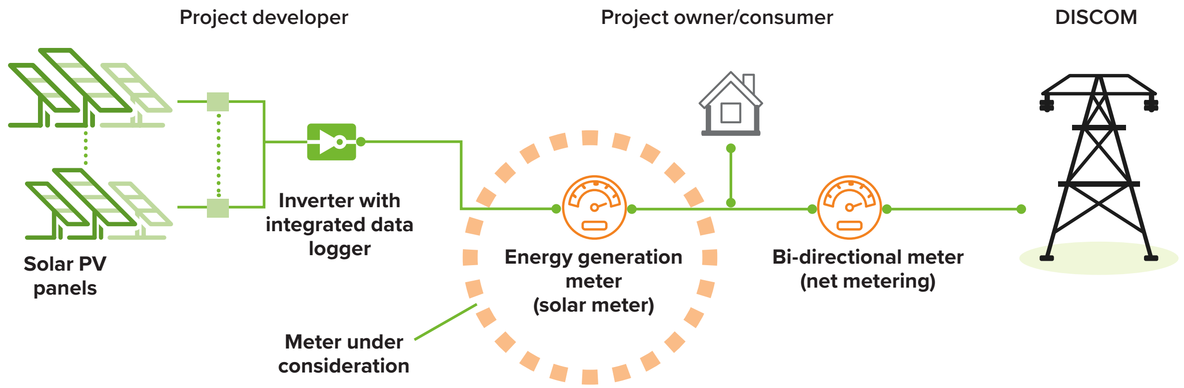
The system was developed as a pilot mitigation action D-MRV to track the electricity generation of rooftop solar photovoltaic systems. DISCOMs previously relied on data from inverter companies, which provided access to integrated data loggers to track generation data. For existing rooftop solar systems, the smart meters in the D-MRV system were integrated with these data loggers. Greenfield solar home systems use smart meters without the need for data loggers.

India's National Institute of Solar Energy (NISE), which falls under the Ministry of New and Renewable Energy, oversaw the implementation and management of the D-MRV system with financial support from the World Bank starting in June 2017. The aim of the system was to streamline certification of emission reductions/mitigation outcomes from a World Bank project. To this end, the D-MRV system monitors and reports data stipulated by CDM-approved monitoring methodology (ACM0002 Grid-connected electricity generation from renewable sources) to determine the amount of emission reductions resulting from the project. The main parameter tracked by the D-MRV system is electricity generated by the rooftop solar photovoltaic system.

The D-MRV reached pilot scale, covering about 40 sites with rooftop solar photovoltaic installations with a total capacity of 9.4 megawatt-peak (MWp). Currently, there are no plans to expand the D-MRV system beyond the pilot stage.

[17] India announced at the Conference of the Parties (COP21) in Paris that it aims to increase to 40 percent the share of installed electric power capacity from non-fossil-fuel-based energy resources by 2030.

**FIGURE 5: ARRANGEMENT OF SYSTEM COMPONENTS IN D-MRV**




## Technical details

A central data monitoring center was set up to aggregate and analyze the data from the 40 sites at the NISE campus in Gurugram in northern India. The pilot data monitoring initiative was conducted with the support of the Chandigarh Renewable Energy and Science & Technology Promotion Society and Chandigarh's Nodal Renewable Energy Agency, with DataGlen as an implementation partner. As part of this pilot, NISE installed data monitoring devices, developed the data-acquisition methodology, and developed a web application for online data analysis and data visualizations.

### Data collected from GRPV systems

The D-MRV system mainly measures electricity in order to accurately calculate the associated emission reductions. However, where the meter is to be placed and what it should measure are equally important.

For GRPV projects, the concept of net metering is a consideration. In GRPV systems, the direct current generated by the solar panels is converted into alternating current by a solar inverter. This is then fed to the building's distribution board before it is consumed by electrical appliances. If the electricity produced is more than what the building consumes, the surplus energy is automatically exported (energy export) to the DISCOM distribution network (the grid) with the help of a two-way meter (bi-directional meter). If the solar energy produced is less than the total energy required in the building, then the shortfall energy is automatically supplied by the grid (energy import). The overall amount of grid electricity displaced is the net electricity generated by the GRPV system. Figure 5 illustrates the arrangements of the D-MRV and GRPV systems.

The smart meter continuously, and in real time, measures net electricity in kilowatt-hours (kWh). These measurements can be reported on a daily, weekly, or monthly basis. The meter integrates with supervisory control and data acquisition software. At the time of piloting, the cost of a conventional meter was about $10 versus $77 for a smart meter. The resulting cost increase for using a smart meter was roughly $67 per connection, increasing the cost of a 1 kilowatt (kW) GRPV by about 12 percent, to $570.

To determine emission reductions from the GRPV systems, the net electricity monitored by the smart meter is the only parameter that needs to be tracked. This measurement is then used to calculate the emission reductions from the project, based on the regional or national grid emission factor.

## Using weather data for QA/QC

The D-MRV system draws on weather data to determine local solar irradiance over a specified period, which is then used to estimate a GRPV system's anticipated performance in a given location. This approach can be used for brownfield projects where conventional meters are used, or to complement smart meter data by ensuring that the reported electricity production system falls within an expected range, given local weather conditions.

## Uses of D-MRV system data

The reporting of the D-MRV system data was streamlined through a web portal showing the performance of GRPV systems across the locations.

While the D-MRV system was initially only used to calculate emission reductions, the data aggregated in the portal was found to have other uses too. Project developers used the data to evaluate the performance of their systems and develop data-backed marketing material.

During the pilot, NISE and the project developers had differing views on the use of the D-MRV data. NISE was in favor of making all system data publicly available to promote solar technologies, while the developers wanted the data to remain private so that competitors could not benefit from it and it could be offered to customers as a paid subscription service allowing them access to their system's real-time power generation data.

# Lessons learned and continued use of digital technologies

There are no plans to scale the D-MRV system beyond the initial pilot of 40 locations providing 9.4 MWp of solar photovoltaic capacity. However, the project yielded worthwhile insights into the use of D-MRV systems and digital technologies.

## Mitigating the cost of digital technologies

For smaller photovoltaic systems (1 kW), smart meters increased the total system cost by 12 percent. The accounting consultancy EY recommended that, given the fixed cost of using smart meters with a GRPV system (an increase of $67 per connection compared with a conventional meter), the benefits of the technology made sense for photovoltaic systems of 3 kW capacity or greater. This would ensure that the increased cost was small relative to the cost of the system. Given that users are willing to pay a subscription fee to access the system's real-time generation data, the cost increase could also initially be carried by the DISCOMs and then recovered through subscriptions.

## Considering the needs of the D-MRV system from the outset

The case study involved both existing and new GRPV installations, so providing insight into the differences between brownfield and greenfield D-MRV projects. The consensus was that it is better to use digital technologies for a greenfield project than to incorporate them into an existing activity, as the use of digital technologies typically comes with increased cost and complexity. If a D-MRV system is to be used, its requirements should inform the project design from the outset.

## The mandated use of smart meters

The D-MRV system was implemented to facilitate the monitoring required under the Program for Results Financing structure of the project. However, the use of smart meters showed benefits beyond these requirements, yielding added value to the DISCOMs and users. As a result, in August 2019 the Ministry of New and Renewable Energy mandated the use of smart meters by DISCOMs for all GRPV systems. Compared to other digital technologies, smart meters are an inexpensive, easy-to-use, and proven technology.

# 3 Uganda's electronic database and information management system

## Type of system: Mitigation action

The electronic database and information management system (EDIMS) is a mitigation action D-MRV system that tracks new grid connections and electricity consumption of those connections using a mobile application, prepaid electricity meters, and a web-based online application. It was developed by RMSI, a global geospatial and engineering firm, for Uganda's Rural Electrification Agency (REA) to support the implementation of a rural electrification program funded by the World Bank.

The goal of the EDIMS is to ensure an optimal, reliable flow of information to allow for the central review, approval, and tracking of connection progress, while allowing for the validation of certified emission reductions generated by the new grid connections under the mitigation action. The D-MRV follows the CDM ex-post monitoring methodology, AMS-III.BL Version 1, to measure emission reductions from electrification of communities. This methodology was revised to accommodate the use of prepaid smart meters to determine the annual power consumption of a connection.

REA is a semi-autonomous body established by the Ugandan government to operationalize its rural electrification function by working with service providers in the country's 12 different service territories. The service providers are private companies that bid for the rights to provide electricity within a service territory. Before the EDIMS, service providers used either paper or electronic records of their electric meters and meter consumption. REA received data on connections and power consumption in the form of Microsoft Excel worksheets.

**FIGURE 6: THE EDIMS WEB APPLICATION**

Development of the EDIMS began in March 2017, with implementation taking place in early 2021. The system currently holds customer and power consumption data on over a million connections throughout Uganda and automatically generates reports on certified emission reductions achieved by service providers for a chosen year.

## Technical details

### Data collection and technologies

In terms of the chosen CDM methodology, projects must track the data points noted in Table 7 for each new connection to the national electricity grid. Before the EDIMS, power blackouts at service provider offices could cause lost data. Duplicate meter numbers were found for different customers when reviewing service provider data. The EDIMS uses multiple digital technologies to allow the prepaid meter to automatically report electricity purchased by the customer, so reducing errors caused by manually recording data and then re-entering it into a database.

### Generation of certified emission reductions

In addition to streamlining data collection and reporting, the EDIMS also calculates the certified emission reductions generated in line with the chosen CDM methodology on electrification of communities. In terms of this methodology, the annual power consumption of a customer is multiplied by a fixed emission factor, which varies depending on the customer's power-usage bracket, to calculate the certified emission reductions. The EDIMS can generate reports for each service provider over a given time period for a verifier to review and certify the emission reductions achieved by the mitigation action. Figure 7 provides a sample of a certified emission reductions report produced by the system.

**TABLE 7: PARAMETERS TRACKED BY THE EDIMS SYSTEM**

| NAME | UNIT | FREQUENCY | MEASUREMENT METHOD |
| --- | --- | --- | --- |
| Power purchased | kWh/month | Monthly | Prepaid smart meters digitally report data to billing system |
| Meter number | – | Once at connection | Recorded through mobile application at time of connection |
| Connection type | Label (household or business) | Once at connection | Recorded through mobile application at time of connection |
| Location | GPS coordinates | Once at connection | Recorded through mobile application at time of connection |
| Connection date | DD/MM/YYYY | Once at connection | Recorded through mobile application at time of connection |

**FIGURE 7: SAMPLE OF A CERTIFIED EMISSION REDUCTION REPORT PRODUCED BY THE EDIMS**

| | | |
|---|---|---|
| Summary Emission Reduction Worksheet | | |
| January to December | | |
| Total Electricity Consumption | 428.95 | MWh |
| Baseline Emissions | 184,450.41 | tCO2e |
| Total Baseline Emissions | 184,450.41 | tCO2e |
| Total Project Emissions for this Monitoring Period | | |
| Grid Emission Factor | 0 | tCO2e/MWh |
| Tranmission and Distribution Losses | 0.1 | fraction |
| Total Electricity Consumed | 428.95 | MWh |
| Project Emissions | 0 | tCO2e |
| Total Leakage | 0 | tCO2e |
| Total Emission Reductions for Monitoring Period | 184,450.41 | tCO2e |

## Data privacy and sharing

There is no concern about data privacy or sharing with the EDIMS because data collected by the D-MRV system is identical to the data collected manually prior to the implementation of the EDIMS.

## Lessons learned and continued use of digital technologies

The D-MRV system at REA was implemented as part of a results-based-financing program with the World Bank, under which the World Bank committed to purchasing certified emission reductions resulting from the extension ofUganda's national grid.

The development of the EDIMS was financed by the World Bank to streamline data collection and reporting of information required to generate the certified emission reductions.

## CDM methodology revision

As already noted, the methodology covering electrification of communities was revised to accommodate the use of prepaid smart meters. Data from prepaid meters technically only shows power purchased, not necessarily power consumed. To allow the use of prepaid meter data, the methodology was revised to stipulate that consumption for a given month is determined by purchases in the previous month. For example, when calculating power consumption for the 2020 calendar year, the EDIMS uses power purchases from December 2019 through November 2020. The methodology assumed that electricity purchased by consumers in Uganda is used within the following month. Updating or revising ex-post monitoring methodologies to adapt to the use of emerging technologies and the data they collect is a significant challenge that needs to be met to enable the use of D-MRV systems.

## Familiar technologies support adoption

New grid connections in Uganda were already transitioning to the use of prepaid smart meters. Combining this technology with mobile applications and an online web application—both familiar technologies—allowed for the development of a fully functioning D-MRV. As such, a large capacity-building effort to train users on these technologies was not required. However, the implementation time of four years (from the project initiation in Q1 2017 to implementation in Q1 2021) required significant commitment of time and resources.

The usage of the EDIMS has exceeded expectations. Initially envisioned to be used mainly by REA and the 12 service providers covering Uganda's service territories, the D-MRV is now also being used by Umeme, Uganda's main electricity provider, which provides power to the service providers and installs new connections.

## Possible future applications

The EDIMS has reduced the cost of collecting and monitoring data for REA's results-based-finance program with the World Bank. While the benefits are only being realized after four years of development, the system provides REA, service providers, and verifiers with easier access to (and greater confidence in) performance reports and generated certified emission reductions. Human error in recording new connections and occurrences of data loss due to power outages are less prevalent.

The EDIMS currently covers more than a million individual grid connections and will continue growing as Uganda works to achieve its electrification goals. Expansion of the D-MRV to cover off-grid solar home systems is also being considered as the mobile applications can easily be modified to collect data on solar home systems at the time of installation, along with the location of the systems.

# 4 Forestry project D-MRV systems

Forestry is a major sector in the work to mitigate the effects of climate change. Tree-planting and forest conservation are often presented as important tools for capturing and storing carbon dioxide emissions from the atmosphere. Projects in this sector have recently benefited from an influx of investment as new digital technologies—such as satellites and drones, AI, and blockchain encryption—make surveying and tracking large areas of remote forest possible for the first time. Developing D-MRV systems for the forestry sector is also crucial because some projects are criticized for attributing too many emission reductions to their activity. A 2021 study estimated that 29 percent of forest projects under California's cap-and-trade system overestimated their climate impact.[18] Accurate and cost-effective D-MRV systems for mitigation actions and GHG inventories for forestry projects could solve this problem.

## Technical details

This case study covers three different D-MRV systems for forestry-related mitigation actions and GHG inventory projects. The systems use digital technologies to track the growth or removal of forests. The three systems are:

- Open Surface MRV in Chile
- Wood Tracking Protocol (WTP) D-MRV in Peru
- Global Mangrove Trust's GROVE: Forestry Smart Ledger in India.

Table 8 summarizes the main characteristics of the various D-MRV systems.

**TABLE 8: FORESTRY D-MRV SYSTEM CASE STUDIES**

| D-MRV | TYPE | OPERATING COUNTRY/ REGION | IMPLEMENTING AGENCY | PARAMETER/S TRACKED (UNITS) | STAGE |
|---|---|---|---|---|---|
| **Open Surface** | Mitigation action/ GHG inventory | Chile | Corporación Nacional Forestal (CONAF) | Area of forest ($m^2$) | Pilot |
| **Wood Tracking Protocol** | GHG inventory | Peru | Swiss Agency for Development and Cooperation | Volume or mass of wood ($m^3$ or ton) | Pilot |
| **GROVE: Forestry Smart Ledger** | Mitigation action/ support | India | Global Mangrove Trust | Area of forest ($m^2$) | Operation |

[18] Reuters. 2021. California Program Overestimates Climate Benefits of Forest Offsets–study. [Online]. Available: https://www.reuters.com/business/environment/california-program-overestimates-climate-benefits-forest-offsets-study-2021-04-30/ [Accessed April 28, 2022].

While the Open Surface and GROVE D-MRV systems support mitigation actions, the Wood Tracking Protocol D-MRV is a GHG inventory system that tracks the harvesting and processing of wood in Peru to combat illegal logging. The GROVE D-MRV uses a blockchain ledger to tokenize areas of forest protected or regrown as part of a project. Each D-MRV is discussed in more detail below.

## Open Surface D-MRV

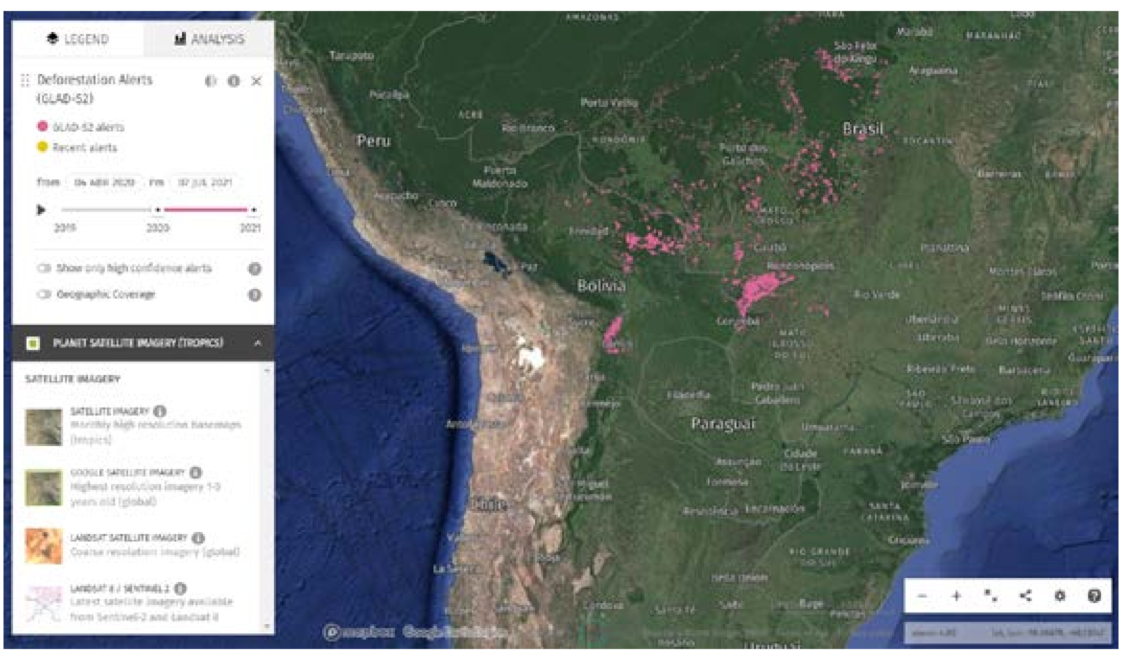
The Open Surface D-MRV is a mitigation action and GHG inventory MRV system. The application can be applied to track reforestation/afforestation efforts (mitigation actions) or to monitor protection of existing forests (GHG inventory). Open Surface D-MRV is a greenfield MRV system that uses AI to comb historical satellite data and compare it with reported deforestation events (such as fire and clear-cutting) to learn which satellite images are indicative of forest destruction. The system is not pursuing carbon finance but could be applied under a reforestation/afforestation project to track forest growth or maintenance. Open Surface is loosely based on Global Forest Watch's tools to determine deforestation. The development of the system is funded by the Inter-American Development Bank and Climate-KIC.

The software underpinning the D-MRV is open source and used by the Corporación Nacional Forestal (CONAF, Chile's National Forest Corporation) to monitor forests in Chile's Valdivia region. The system tracks 100 $m^2$ areas of land every three to five days—when the satellite passes over the area again. Over a one-year period, this equals about 500 million data points in the pilot region.

CONAF uses Open Surface's AI software to comb vast amounts of satellite data to detect and report loss in forest cover. Prior to the D-MRV system, CONAF would send a team to the site to evaluate deforestation reports. As a result, the AI had data on historical deforestation events that it could match to changes in satellite images when the event occurred. This allowed the system to learn how different events affect the data, so enabling it to detect deforestation. Figure 8 shows a map of recent deforestation events in South America from the Global Forest Watch data portal.

[19] Global Forest Watch. No date. Explore Our Data. [Online]. Available: https://www.globalforestwatch.org/map/ [Accessed April 28, 2022].

**FIGURE 8: GLOBAL FOREST WATCH DATA PORTAL**[19]



Under the pilot, the educated AI analyzes satellite data and, if an event is detected, the location is checked against the database of areas marked for deforestation. If the location is not exempted, the incident and location are flagged for inspection by CONAF.

Before piloting Open Surface, forests were monitored on a rotational basis. The COVID-19 pandemic provided an extra push towards accepting remote, digital processes. Adopting digital processes had the added benefit of enabling monitors to prioritize flagged forest areas and conserve limited staff resources for on-site visits.

The main benefit of the D-MRV system is the ability to track a large area without requiring physical inspection. The downside is the relatively high cost of AI expertise and access to the satellite data. The initial set-up also posed the challenge of consolidating data from land-usage plans that, although digital, were stored in different formats.

After piloting, the system will be expanded across Chile and to other Latin American countries or regions.

### Wood Tracking Protocol D-MRV in Peru

It is estimated that more than 80 percent of wood from Peru is illegally harvested. The WTP is built on top of an existing MRV system implemented by Peru to enforce rules and regulations on harvesting wood and to combat illegal logging. The pre-existing MRV relied on on-site inspections and hardcopy documentation of the dimensions of trees and which trees could be harvested. The D-MRV digitized established procedures required to track wood use, per the logging guidelines of Peru.

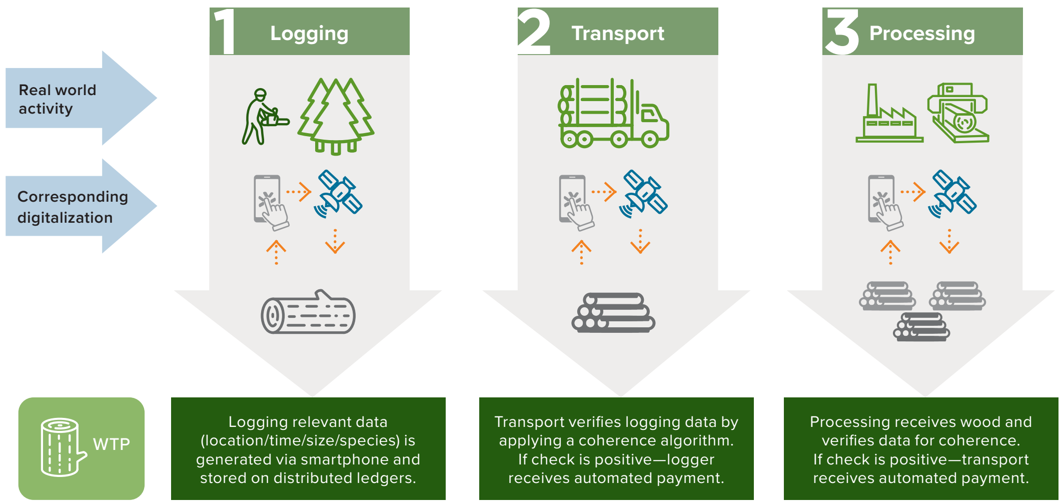
The WTP is not supported by carbon credit finance because it does not directly track emission reductions. The D-MRV system hopes to combat illegal harvesting of wood in Peru by providing assurance to buyers of wood products that their purchases adhere to national guidelines. This will likely reduce deforestation and avoid GHG emissions since deforestation is the main source of GHG emissions in Peru.

The WTP is owned and funded by the Swiss Agency for Development and Cooperation through the Climate Ledger Initiative. The pilot phase of the D-MRV covers the Peruvian Amazon region and the main parameter tracked is cubic meters or tons of wood. For conversion between mass and volume of wood, only the density of the species needs to be known.

The WTP uses a smartphone to measure and tag trees that are allowed to be harvested. The landowner uses an application to tag the tree to be harvested with a picture, its GPS location, and key measurements to estimate the tree's volume, in line with Peru's national guidelines. In Peru, cellphone numbers are linked to a person's national identity number so there is assurance that data is coming from the landowner.

The WTP then uses blockchain technology to securely track the wood from harvested trees as it moves through the supply chain. After being designated for harvesting, the tree and its volume are logged in the blockchain ledger. The person cutting the tree follows a similar process, using the application to record the volume of wood harvested as well as where it will be transported for processing.

**FIGURE 9: WOOD TRACKING PROTOCOL D-MRV PROCESS DIAGRAM**[20]




This process repeats throughout the supply chain, as shown in Figure 9, allowing wood buyers to track where the wood comes from and be assured that the tree was legally harvested. In future, the D-MRV could scale nationally and leverage satellite data and AI to complement current data. It is also envisioned that payment for the tracked wood will be automated through the application when predetermined milestones are reached.

## GROVE: Forestry Smart Ledger

Mangrove forests have the ability to capture more carbon dioxide than rainforests, usually at a lower cost.[21] GROVE: Forestry Smart Ledger is an open source, greenfield D-MRV being rolled out in India that tracks both the flow of funds to mangrove conservation projects (support) and the impact of mitigation actions by such projects.

GROVE: Forestry Smart Ledger is championed by Global Mangrove Trust, a non-profit based in Singapore that aims to improve the financial viability of mangrove conservation projects by making access to carbon finance easier, reducing monitoring and verification costs, and using smart contracts to ensure financial transparency while ensuring that local communities benefit from the projects. Global Mangrove Trust's goal is to "plant as many trees, as quickly as possible".[22] To accomplish this, it is working to create an enabling environment for mangrove conservation projects by supporting digital monitoring technologies and methodologies, as well as innovative financing.

The GROVE: Forestry Smart Ledger D-MRV system uses satellite data and AI to measure and verify mangrove conservation and growth projects. The system also has a fintech component, going beyond monitoring, reporting, and verification to connect mangrove projects with funders through GRO-coin, a blockchain-backed, non-fungible digital token.

Figure 10 shows how GROVE: Forestry Smart Ledger is made up of two components: GROVE, the blockchain-backed platform that connects funders with projects and tracks the flow of money, and Forestry Smart Ledger, which runs machine learning algorithms on satellite data of forest growth to measure the impact of project activities and create smart contracts underpinning GRO-coin.

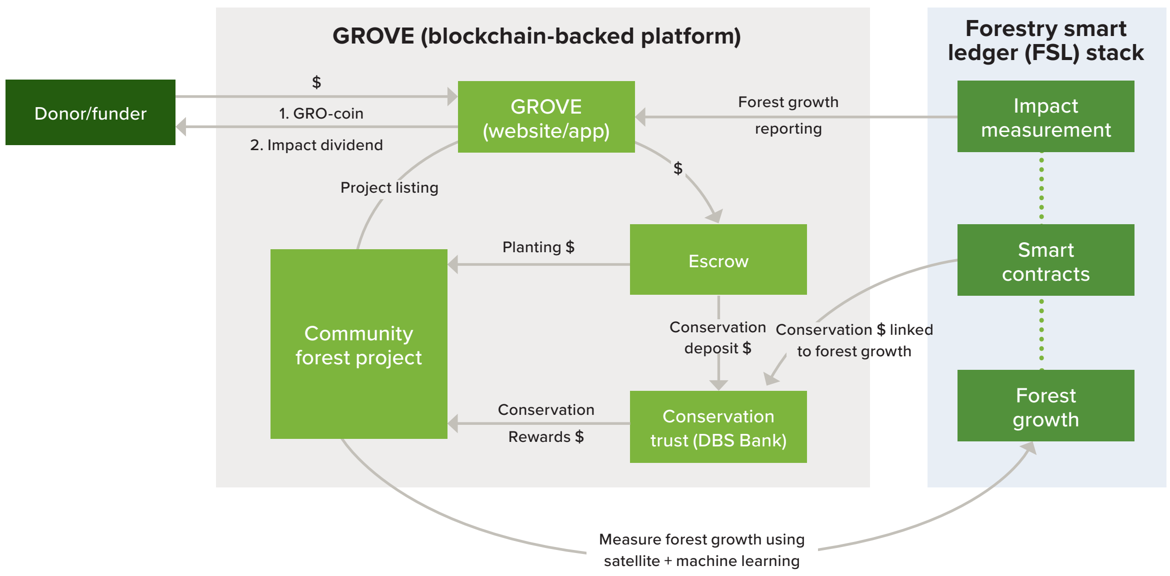
---

[20] Wood Tracking Protocol. No date. Blockchain WTP. [Online]. Available: https://wtp-project.com/ [Accessed April 28, 2022].

[21] Climate Finance Lab. No date. GROVE: Forestry Smart Ledger—About. [Online]. Available: https://www.climatefinancelab.org/project/grove-forestry-smart-ledger/ [Accessed April 28, 2022].

[22] Global Mangrove Trust. No date. What is GMT? [Online]. Available: https://globalmangrove.org/ [Accessed April 28, 2022].

## FIGURE 10: GROVE: FORESTRY SMART LEDGER DESIGN[23]




The D-MRV does not follow a specific monitoring methodology and can be adapted to work with most available forestry and soil carbon methodologies. GROVE: Forestry Smart Ledger is being rolled out in India, but Global Mangrove Trust sees potential for it to be used across Southeast Asia for mangrove and other forestry or soil carbon projects.

## Lessons learned and continued use of digital technologies

### Training and automating complex tasks

All three D-MRV systems discussed in this section have plans to improve on and expand their use of technology. This could result in higher system development costs and increase the need for training. For example, the smartphone application developed by the WTP was initially difficult for landowners in rural Peru to understand and use effectively. Landowners were willing to use it when they were shown how the application simplified the process of designating trees for harvesting. However, entering the dimensions of a tree into the application in order to estimate the total volume of wood remains a challenging task. The WTP team hopes that using new smartphone models with multiple cameras and AI will help automatically determine the tree's volume more accurately while requiring less input from the user. The combination of improving the user experience and incorporating payment options in the application will further promote adoption of the WTP by landowners, lumber companies, and buyers.

### Drones and scaling AI to other climates

The Open Surface D-MRV team plans to complement satellite data with images from low-flying drones and to improve their AI. Drones can provide higher-resolution images of areas where satellite data has prompted the AI system to report a deforestation event. The use of low-flying drones is currently costly, considering the small area a drone can cover relative to satellite data.

[23] Climate Finance Lab. No date. GROVE: Forestry Smart Ledger—Design. [Online]. Available: https://www.climatefinancelab.org/project/grove-forestry-smart-ledger/ [Accessed April 28, 2022].

Scaling an AI-backed D-MRV to other regions and climates that have different colors and patterns of plants, soil, and weather presents a challenge because the AI needs to relearn the relationship between satellite images and deforestation events. A further challenge highlighted by the Open Surface team is that while the D-MRV system can identify false positives—in other words, where a deforestation event is reported but no deforestation is found on inspection—the system cannot easily identify false negatives (unreported deforestation events) because these are not inspected.

## System-wide verification and data-sharing issues

The cost of monitoring and verifying mitigation actions is often seen as limiting the viability of emission reduction tracking. Typically, each project needs to engage in the MRV process on an annual or biennial basis. D-MRV systems can reduce the time and cost of these processes.

To realize this benefit, the team behind GROVE: Forestry Smart Ledger is working towards a one-off, system-wide verification so that any projects using the verified system are automatically deemed verified, and emission reductions can be certified as project data is recorded. Global Mangrove Trust is working with the Smith School of Enterprise and the Environment at the University of Oxford, Kumi Analytics, and Marex to develop a sequestration methodology that relies on remote verification, backed by machine learning, to make verification quick, accurate, transparent, and in real time.[24]

One of the hurdles faced by GROVE: Forestry Smart Ledger is a lack of transparent historical data showing reforestation progress and growth rates. GROVE uses this data to test and train its machine learning models. Global Mangrove Trust described a lack of willingness by organizations with this data to share it, citing legal or financial reasons. This data can understandably be deemed sensitive as it shows the numbers underlying project performance of forestry projects and could invite scrutiny on a project's performance or implementation. The lack of test data to use for training models could be an impediment for scaling this technology. Open Surface circumvented this problem because the implementing partner, CONAF, owns the data used by the machine learning model.

## Forest projects need D-MRV the most

Regrowing and maintaining the Earth's forests are important tools for reducing carbon dioxide emissions. It is estimated that forests and other ecosystems can make up a third of the required reduction in emissions to stay below 2°C.[25] But mitigation activities on forestry have unique challenges that D-MRV systems can address.

Emission reductions from conservation, afforestation, or reforestation are treated differently than those from other mitigation actions, such as renewable energy, efficiency measures, or switching fuel. This is because of the question of permanence. Carbon dioxide captured in a tree can be released back into the atmosphere in the event of a fire. This is unlike other mitigation actions, which permanently avoid more carbon-intensive alternatives. In addition, power plants or factories already report their generation, fuel usage, and other metrics, while forests are largely not tracked or monitored at the macro level.

The technologies used for D-MRV for forest projects also bring positive spillover effects into complementary areas. CONAF found it valuable to have consolidated visual information that combined historical views of the forests that were not previously available. All of the use cases use the system to assist with optimizing in-person monitoring activities, and Mangrove Trust uses the data to determine where new trees should be planted to achieve the greatest impact.

For these reasons, robust and transparent D-MRV systems are highly important for forestry projects. Since 2018 there has been growing interest in investing in digital technologies to build cost-effective D-MRV systems, with an increase in venture capital for start-ups working in the space (Figure 11). The three case studies in this section are illustrative of the technologies being used to monitor forests, forests' carbon stocks, and the movement of funds.

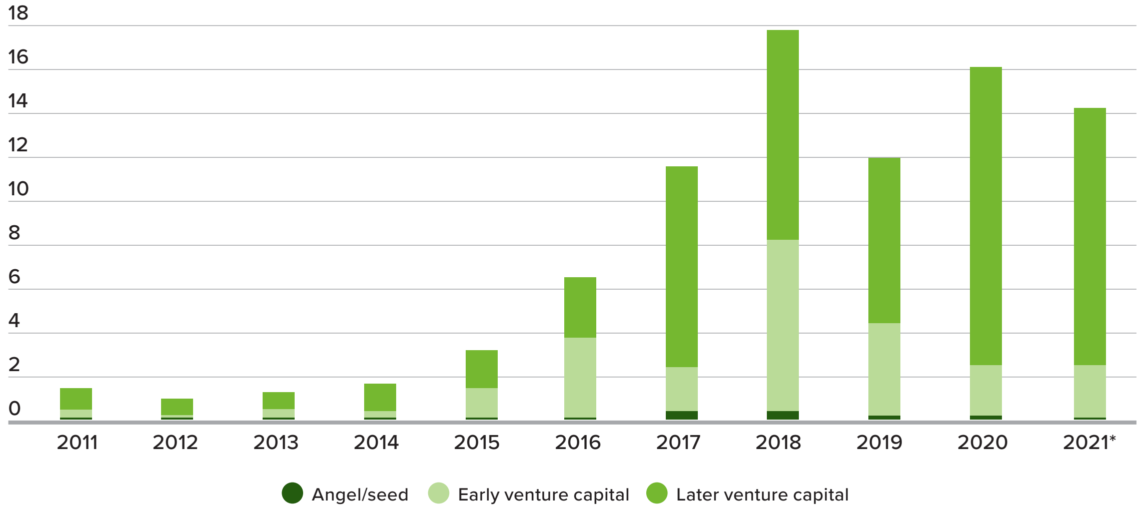
---

[24] Global Mangrove Trust. No date. What is GMT—Our Current Partnership. [Online]. Available: https://globalmangrove.org/ [Accessed April 28, 2022].

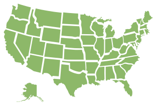
[25] Griscom, B. W., Adams, J., Ellis, P. W., et al. 2017. Natural Climate Solutions. Proceedings of the National Academy of Sciences of the United States of America. PNAS: Washington, DC. [Online]. Available: https://www.pnas.org/doi/10.1073/pnas.1710465114 [Accessed April 28, 2022].

## FIGURE 11: VENTURE CAPITAL FUNDING FOR CLIMATE TECH START-UPS

**Global venture capital deal flow in climate tech ($ billion)**




Global investors have closed as many climate-focused funds in 2021 as the previous five years combined.



Seventeen US states, the District of Columbia, and Puerto Rico have adopted policies aiming to move to either all-renewable or zero-emission electricity supplies.

The US officially rejoined the Paris Agreement in February 2021. The Biden administration aims to spend $2 trillion over four years on clean energy sources, with a goal of reaching net-zero emissions by 2050.

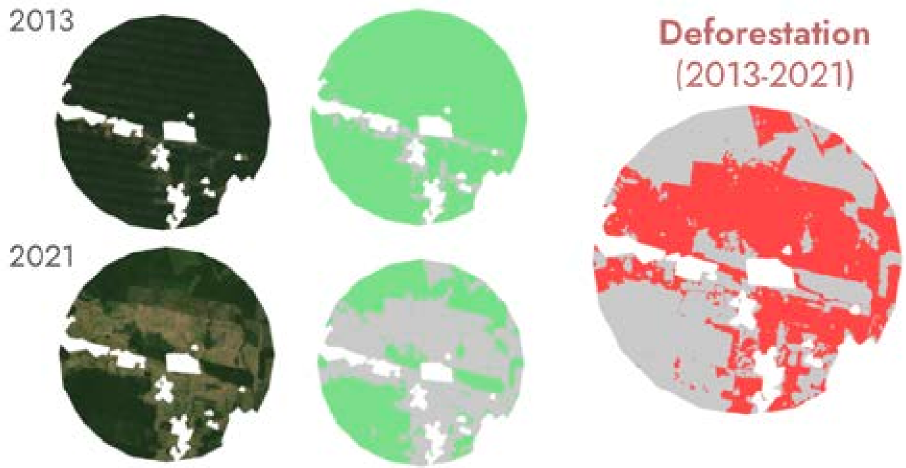
*Source:* PitchBook
*As of June 25, 2021

# 5 Third-party ratings of nature-based carbon credit projects

Private companies are using D-MRV systems to provide ratings of carbon credits and the projects they are generated from. Sylvera is an example of such a company and uses emerging digital technologies to produce independent ratings of nature-based carbon crediting projects. The company has developed machine learning models that interpret multispectral satellite data to estimate key parameters such as above-ground biomass and changes in forest cover across project areas. These outputs come with a level of uncertainty that can be significantly reduced by integrating on the ground data, which will be gathered using LiDAR scanning.

Legacy MRV methodologies for forest crediting projects rely on manual assessments of sample areas within a project, which are then extrapolated across the project, with monitoring undertaken every few years. Sylvera's system accesses raw satellite earth observation data from across entire project sites, as frequently as satellites pass over (usually every two to four weeks). This geospatial data is fed to machine learning algorithms, which analyze and visualize this data, allowing for up-to-date assessments of forest cover and condition. Historical satellite data of the project site is also available, allowing for baseline assessments and better understanding of risks to permanence such as fire history.

**FIGURE 12: SATELLITE IMAGERY OF FOREST COVER (GREEN) IS COMPARED TO TIME SERIES DEFORESTATION DATA (RED), WITH OTHER DETECTED LAND CLASSES, SUCH AS WATER, ROADS, AND SETTLEMENTS (WHITE)**



Sylvera is also using new technology to gather more accurate on the ground data to train the machine learning models. Current methods for estimating forest above-ground biomass, and therefore carbon stored, rely on allometric models. Estimates from these methods can have potentially large uncertainties, often upwards of 40 percent at the stand-scale,[26] particularly in the world's tropical and subtropical forests. Sylvera's second-generation machine learning models are trained using proprietary datasets gathered using multi-level LiDAR scanning, which significantly reduces the uncertainty of above-ground biomass assessments.

This data is used to improve the accuracy of Sylvera's machine learning models. Sylvera combines quantitative and qualitative data from carbon projects to rate the performance of carbon credits on a scale of AAA to D, similar to how financial bonds are rated. This is calculated based on the project's rating in three areas:

- Carbon score (emissions reduction achieved compared to the credits issued)
- Additionality (the extent that results would not have occurred without the project)
- Permanence (how long the benefits will last).

The project is also rated for its community and biodiversity co-benefits. The project's deliberate contributions to the local community are assessed in terms of their alignment with the United Nations Sustainable Development Goals. Data from project developers and geographic information system (GIS) mapping, along with local research, is used to assess the project's contributions to species richness and diversity and biodiversity protection in the context of local, regional, and national threats.

## Organization, support, and current status

Sylvera is a United Kingdom-based start-up founded in March 2020. Revenue is generated through subscription to Sylvera's ratings and analysis data, available to clients through a web application and via an API.

Sylvera received seed funding from venture capital firms, along with a research grant from Innovate UK's Small Business Research and Innovation program. This grant funded proof-of-concept and initial field work using LiDAR to gather on the ground above-ground biomass data in Gabon and Peru. In early 2022, Sylvera raised an additional $32.6 million in venture capital and private equity funding.

Sylvera receives technical support from several areas. The company partnered with Dr António Ferraz (the University of California in Los Angeles and the NASA Jet Propulsion Laboratory) and Professor Mathias Disney (University College London) on the use of LiDAR. Through the SPace Research and Innovation Network for Technology business support program, Sylvera also collaborated with the University of Leicester in the United Kingdom to verify its machine learning methodology.

[26] Picard, N., et. al. 2015. Reducing the Error in Biomass Estimates Strongly Depends on Model Selection. Annals of Forest Science. doi: 10.1007/s13595-014-0434-9

## Technical details

### Data sources and pre-processing

Sylvera accesses open-source, multispectral satellite data from Google Earth Engine, including optical data from satellites and topographical ranging data from the Global Ecosystem Dynamics Investigation LiDAR instrument on board the International Space Station.

This data has global coverage, with spatial resolutions that vary from 10 meters to 30 meters. Data is calibrated and pre-processed to reduce artefacts and achieve a clear image for each region.

### Use of data

Land class is labeled using the 2019 Global Forest Canopy Height dataset, with additional segmentation labels for training and validation provided by CloudFactory, which specializes in annotations for machine learning. This on the ground data is used to train and validate deep-learning models to interpret optical satellite images and apply a binary "forest/ not forest" mask, considering the local definition of forest. These models can then be used to track forest cover in project areas, as well as reference and leakage areas, over time. Data can be updated as often as satellites pass over project sites. Forest/ not forest predictions are used to calculate both the carbon score and additionality ratings.

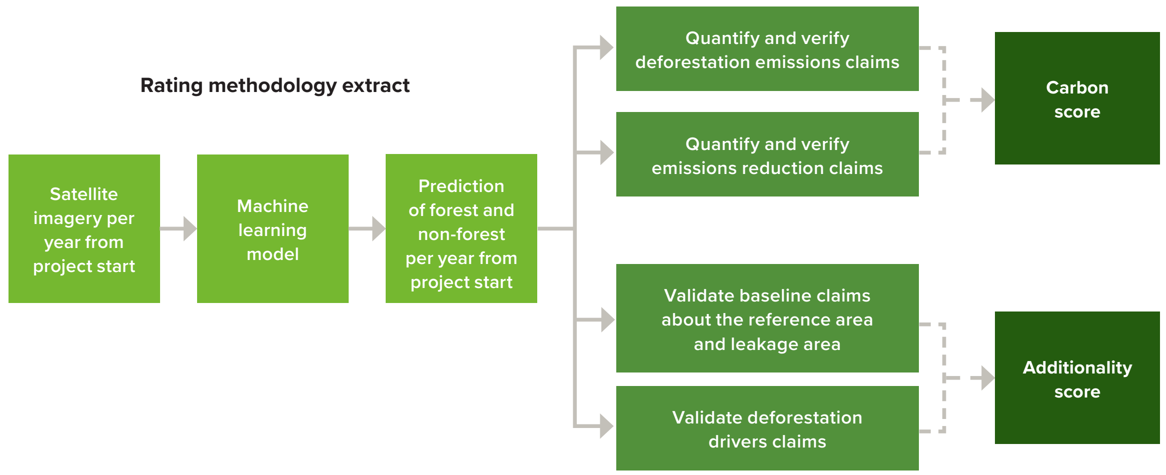
### Quality assurance

Quality assurance is performed at several stages. Internal machine learning QA validates predictions by comparing datasets to global and local data on forest cover. The machine learning outputs are assessed by the GIS team before being fed into the ratings framework. Visual QA is performed by comparing machine learning predictions with satellite images and time series plots.

### Improved biomass data to train machine learning models

Inferring reliable pixel-wise above-ground biomass values from satellite data requires accurate on the ground data to calibrate the machine learning models. Legacy methodologies to collect this data use allometric models based on manual sampling of tree height and diameter at breast height to estimate forest above-ground biomass. Validation studies using destructive methods, where model predictions are compared to direct measurements of the biomass of felled trees, have shown these models to underestimate above-ground biomass (except for when measuring coniferous forests). When scaled across a one-hectare (ha) stand, these measurements also result in an uncertainty rating of up to 40 percent.[27]

**FIGURE 13: OVERVIEW OF HOW SYLVERA'S MACHINE LEARNING OUTPUTS FEED INTO THE RATINGS OF CARBON SCORE AND ADDITIONALITY**




[27] Demol, M., et al. 2022. Estimating Forest Aboveground Biomass with Terrestrial Laser Scanning: Current Status and Future Directions. Methods in Ecology and Evolution. https://doi.org/10.1111/2041-210X.13906

Sylvera's approach to this problem is to gather biomass data using multi-level LiDAR scanning and volumetric tree modeling. Terrestrial LiDAR scanning maps vegetation across three single hectare sample plots to millimeter detail, collecting about 400,000 data points per square meter. This is scaled up using drone-mounted, unoccupied aerial vehicle-based LiDAR scanning 1,000 ha and upwards of 50,000 ha in slow- and fast-flying configurations. The 3D models of tree and forest structure derived from the data enable estimates of above-ground biomass with significantly improved accuracy.

**FIGURE 14: SYLVERA'S TERRESTRIAL LASER SCANNER MAPPING VEGETATION IN THE PERUVIAN RAINFOREST**

**FIGURE 15: POINT CLOUDS OF INDIVIDUAL TREES INSIDE AN AFRICAN TROPICAL FOREST STAND, CAPTURED USING TERRESTRIAL LiDAR SCANNING**

Sylvera's research team, in partnership with the World Bank, University College London, the University of Edinburgh, and NASA's Jet Propulsion Laboratory, have so far conducted research in the African tropics, the South American tropics, and temperate forest, funded by the Small Business Research and Innovation grant. Future research aims to cover all biomes relevant to their rated projects, with plans to collect measurements from 20 to 24 more sites across 10 countries in the coming years.

## Lessons learned and continued use of digital technologies

### D-MRV verification

The SPace Research and Innovation Network for Technology supported Sylvera in developing and verifying its methodology and quantifying uncertainty. Together with a team from the University of Leicester, a transparent method of validating the machine learning outputs and subsequent interpretations has been identified in order to increase credibility and confidence in the credits rating framework. This work is being continued to consider possible changes in data sources and how they might impact estimates and uncertainty.

### Future developments

Initial ratings focused on avoided tropical deforestation projects. To expand the range of biomes and crediting projects covered, the machine learning models are being updated to go beyond binary classifications to include sparse forest, mangroves, plantations, and canopy cover and height. The next iteration of models will output continuous definitions such as the percentage of tree cover, allowing activities such as forest degradation and vegetation growth to be monitored, and for afforestation, reforestation, and revegetation and improved forest management projects to be rated.

When tracking large-scale activities in forests such as clear cuts or forest fires, public data is suitable as it has sufficient resolution, is extremely well calibrated, and is available with global coverage. To track small-scale activities such as selective logging and degradation, high-resolution imagery is required, which could be obtained from commercial companies. Access to this higher-resolution data could also help overcome some challenges faced by the machine learning models in expanding project cover, including seasonality, mountains, cloud cover, and variability of vegetation.

New models are being developed to cover other types of nature-based crediting projects that have previously lacked accurate MRV. These include models tracking soil carbon and blue carbon crediting projects. The robust ratings framework can be used to assess the additionality, permanence, and co-benefits of wider crediting projects included in voluntary carbon markets, such as renewable energy and cookstoves. Through partnerships with the World Bank and national governments, Sylvera's D-MRV systems will also be used as part of jurisdictional REDD+ programs and wider carbon accounting.

### Policy considerations

Sylvera's stated mission is to "deploy state-of-the-art D-MRV systems to restore confidence in nature-based solutions and help quickly scale VCMs [voluntary carbon markets]". Its rating framework aims to address a key criticism of avoided emissions credits from nature-based projects, which is that the carbon benefits are poorly quantified and unreliably reported. More accurate assessments of the carbon stored in the world's standing forests allows them to be properly valued, and accurate, real-time monitoring of their condition allows fair results-based payments to be made, incentivizing national governments and local communities to conserve forests.

# 6 European Bank for Reconstruction and Development D-MRV system for renewable energy

## Type of system: Mitigation action

The EBRD D-MRV system is being piloted in support of two broad use cases: results-based climate finance provided by the Spanish Climate Change Office for a grouped solar project in Jordan, and climate finance impact reporting to the Clean Technology Fund (CTF) under the EBRD program on Accelerating Innovations in Renewable Energy, co-financed by CTF. An initial set of solar plants in Jordan has been integrated into the D-MRV as of the end of 2021. This case study is thus based on initial experiences gained with these plants only.

The fully functional D-MRV system, which was developed in 2021, applies the key principles and requirements laid out in the D-MRV Protocol,[28] which was released by EBRD at the end of 2020 and builds on the inputs from members of the Joint Multilateral Development Banks Working Group on Article 6.

The D-MRV system serves a portfolio of eight solar photovoltaic plants with a total capacity of 48.3 MWp that is run by Yellow Door Energy Jordan (YDE).[29] This is Jordan's largest portfolio of private-to-private renewable energy plants supplying directly to the private sector. The YDE project has been registered with the VCS[30] as a grouped project and, as such, benefits from results-based payment from the Spanish Climate Change Office, in effect monetizing its mitigation outcomes (up to an agreed limit). The resulting GHG emission reductions paid for under this arrangement have to be monitored, reported, and verified by the EBRD's D-MRV system. The objective of the D-MRV pilot is to showcase how digitalization and automation of MRV processes—with associated benefits in terms of reduced costs and time, and increased accuracy and transparency of data—could facilitate scaling up of mitigation actions under the existing and emerging carbon market mechanisms and results-based climate finance instruments.

The D-MRV system was developed by BowTie Technology BV, under contract to EBRD. It is a cloud-based software solution that enables on-site, measured data to be directly acquired from renewable energy projects and automatically sent for validation and cross-checking. GHG emission reductions are then automatically calculated according to the applicable methodology, and monitoring reports on system-verified GHG emission reductions are generated. The main parameter monitored is the net electricity generated and supplied to the grid, with solar irradiance data also tracked for the purpose of cross-checking the power output.

---

28 European Bank for Reconstruction and Development. Protocol for Digitalised Monitoring, Reporting and Verification (D-MRV Protocol). December 2020. [Online]. Available: https://www.ebrd.com/documents/climate-finance/digitised-mrv-protocol.pdf?blobnocache=true [Accessed April 28, 2022].

29 Yellow Door Energy. No date. Projects. [Online]. Available: https://www.yellowdoorenergy.com/projects/ [Accessed April 28, 2022].

30 Verra. No date. Grouped Solar Projects in Jordan. [Online]. Available: https://registry.verra.org/app/projectDetail/VCS/2016 [Accessed April 28, 2022].

Implementation of the YDE solar photovoltaic project in Jordan was carried out over several years, with the first plants completed in 2019 and the full portfolio expected to be finalized in late 2022. The D-MRV system launched in September 2021 was connected to the plants that were operational at the time. The D-MRV piloting phase is expected to continue through to 2023 to allow for the remaining plants to be commissioned and to verify delivery of the targeted mitigation outcomes under the results-based arrangement. This phased rollout will also allow for insights into real-time monitoring and connectivity issues to be identified and used to enhance efficiency and robustness of data validation and cross-checks (including, potentially, exploring options for applying machine learning).

The initial results of the pilot, which are broadly summarized in this case study, indicate strong potential for D-MRV to enhance the efficiency, timeliness, accuracy, and transparency of MRV processes.

## Technical details

### The use of digital technologies for data collection and processing

The D-MRV system relies on a set of digital technologies to monitor and collect the data on the relevant parameters. Electricity supplied to the grid, and consumed from the grid to power internal loads during non-operating hours, is continuously measured by revenue-grade, on-site, bi-directional digital electricity meters at five-minute intervals, with time-stamped readings delivered via a server to the D-MRV cloud environment. This enables the system to calculate the project's net energy generation, which is the key input into the calculation of the mitigation results achieved. The other key input into the GHG mitigation—grid emission factor—is preset ex-ante defined in the registered VCS project documentation and is not monitored. In parallel, solar irradiance is measured by on-site pyranometers and acquired via the same process to enable cross-checks of the main output parameter.

The D-MRV software and data are hosted in the industry-class cloud, which ensures scalability, flexibility, and high system availability. Information security is assured through data encryption, both in transit and at rest. High-frequency data retrieval, which sees measurements taken at five-minute intervals and data pulled into the D-MRV on an hourly basis, helps to prevent potential data tampering as it limits the "non-supervised" time the data spends at the project site before being transferred to the secure D-MRV environment. The system's credibility and transparency are further assured by the use of cloud-native, immutable storage of the raw data, allowing full traceability of raw data for the purpose of verification. Access to the D-MRV system is restricted to preauthorized users, with their rights to access and/or handle data and perform certain functions defined broadly in line with the relevant provisions of the D-MRV Protocol. For example, YDE, as the project owner, mostly has read-only access, particularly to critical elements that may compromise the integrity of the results claimed.

### D-MRV system data verification

In addition to automatically acquiring data in near real time, the D-MRV system performs quality assurance and verification of the data received in several ways. First, data provenance is assured by the use of authenticated data sources, which are configured in the D-MRV system from the outset, so preventing potential tampering at the point of data import. Second, the data undergoes several numeric checks for completeness and consistency on arrival in the D-MRV to detect and fill data gaps or irregularities. Finally, the D-MRV conducts a plausibility cross-check to ensure that the monitored energy produced does not exceed the theoretical maximum output based on the plant's configuration and the solar irradiance available over the period covered.

Depending on the outcome of the above checks, the D-MRV system automatically labels each data point as "auto-approved", "pending", or "rejected". This significantly streamlines periodic verification by an auditor, as only the "pending" data points will need to be manually approved or rejected (although all data points are available to the auditor for review, if needed).

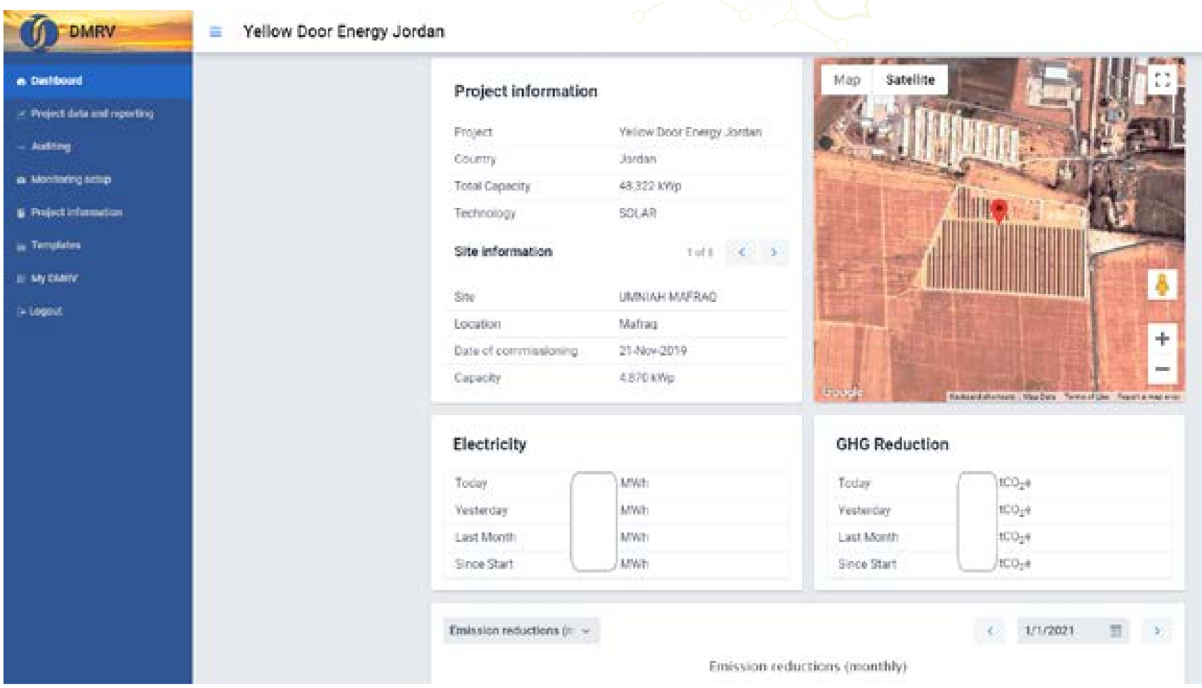
In order to facilitate remote verification of the project's claimed mitigation results, the measured data directly acquired by the D-MRV system is supported with additional digital records that are manually uploaded to the system, including geotagged site photos, metering diagrams, meter calibration, and power plant commission certificates.

### Data presentation and reporting

The D-MRV system presents data in two ways: via a dashboard and via a reporting interface. The reporting interface supports data reports (downloadable worksheets for any parameter handled by the system) and GHG emission monitoring and verification reports. While the dashboard provides a quick overview of the key project performance indicators in numeric and graphic form, deeper insights can be gleaned through the data reports.

The GHG monitoring and verification report is intended to enable the monetization of mitigation outcomes claimed. The report automatically draws information—including energy generation, calculated GHG emission reductions for the selected monitoring period, and manually entered narrative data—from the D-MRV database and combines it in a familiar VCS-type report without requiring additional manual intervention. Combined with system-generated data quality and approval labels, as well as verification feedback of an auditor (provided via dedicated auditor access to the system), the report could be finalized in the system and immediately shared (for example, via an API) with the respective environmental attribute standard for an issuance decision.

**FIGURE 16: EBRD D-MRV STRUCTURE**




*Note:* Some data has been hidden for confidentiality reasons.

## Methodological modifications to D-MRV approach

The YDE project registered with the VCS relies on the "standard" CDM methodology for grid-connected electricity generation from renewable sources, ACM002, for the monitoring and accounting requirements to calculate its GHG mitigation results. While the methodology and the associated tools mandate that the key parameter (quantity of electricity supplied to or consumed from the grid) should be measured by electricity meters installed at the grid interface, these meters are inaccessible to the project company—and hence, to the D-MRV system—for remote communication, as is the case with most commercial utility-scale renewable energy projects. The D-MRV system therefore relies on plant-site check meters that are under control and used by the project company for plant-monitoring purposes. The check meters installed are of revenue grade and accuracy class, which makes them suitable for the purpose of D-MRV system monitoring.

In order to accurately account for the actual amount of net electricity generation fed into the grid, as would be measured at the grid interface, the unavoidable cabling and transformer losses between two sets of meters—grid-side utility and plant-side check meters—had to be included in the methodology-prescribed calculation approach to avoid overstating the results. The corresponding losses have been conservatively estimated, based on the pre-D-MRV period electricity generation data (from both sets of meters), and embedded into the D-MRV calculation algorithm.

## Lessons learned and continued use of digital technologies

The current D-MRV pilot started in September 2021. Some early insights gained from monitoring the operational portfolio are summarized below.

### Onboarding new projects

In order to fully realize the cost- and time-savings benefits that the D-MRV offers, it is essential that the process of connecting new projects to the D-MRV system is streamlined and automated to the extent feasible. The set-up of the pilot YDE project was handled manually by the developer, in coordination with the project owner, which took a fair amount of time. Going forward, a (semi) automated on-boarding process will be trialed for new projects, whereby some or most of the project's elements will be configured in the D-MRV based on inputs provided by the project owner. This is expected to significantly reduce the duration and cost of the project set-up stage.

### Advanced verification approaches

The pilot D-MRV system implemented some basic verification checks to ensure that the energy production numbers fall within the expected performance range, based on a plant's respective configuration, capacity, and efficiency, combined with solar irradiance, among other metrics. As currently designed, these checks have limitations. For instance, they are "hard-coded" for each plant and have, at times, triggered "false positive" flags when plants were suspected of producing output that exceeded their rated capacity (which could happen due to a combination of factors such as high irradiance, the module temperature, and the angle of the sun). The ongoing piloting phase is refining these cross-correlation checks to arrive at a more robust, flexible, and potentially more scalable approach. One alternative could be a machine learning model that can be "trained" on a set of trusted data in order to then provide continuous plausibility assessment for energy production and help better detect potential data anomalies.

## Interoperability with other MRV systems

The EBRD D-MRV system operates with near real-time, high-resolution raw data and should be able to exchange this data with other stakeholders. However, such high-resolution data (for example, GHG emission reductions at five-minute intervals) could prove excessive and are probably not necessary for other MRV systems, such as a national-level GHG reporting and inventory system. Nevertheless, the two types of MRV systems can be integrated, for example, by having the project-level D-MRV system pass on aggregated data at an agreed resolution (for example, monthly energy generated and mitigation results achieved) to the national-level MRV system through an API. The compatibility of the systems will need to be ensured by using the same emission factors, as an example. The ongoing D-MRV pilot will explore these issues on the basis of the YDE project, as well as potential connectivity options with the national MRV system in Jordan.

## Alternative measurement arrangements

As evidenced by the ongoing D-MRV pilot, and as is likely the case for other commercial renewable energy projects, remote access to billing meters at interconnection points may not be available to project owners and/or D-MRV system operators. As a result, alternative measurement hardware with appropriate metering and communication capabilities may need to be put in place. Energy losses between two measurement points need to be reflected when calculating the net energy exported and GHG impacts claimed by the project. This will limit the ability for direct cross-checking against digital billing system records due to obvious discrepancies in readings between the two metering points.

The ongoing pilot will provide further insights into this issue as new projects are connected, different interconnection configurations are analyzed, and clarity is achieved on the requirements for the measurement and communication hardware. These learnings are expected to feed into updates of the respective provisions of the D-MRV Protocol.

# Appendix

### TABLE 9: COMMONLY MONITORED PARAMETERS AND CORRESPONDING DIGITAL TECHNOLOGIES

| PARAMETER | DESCRIPTION | RELEVANT MITIGATION ACTIONS | DATA UNIT | MONITORING FREQUENCY | MONITORING METHOD/S | DIGITAL TECHNOLOGY | QUALITY CONTROL |
|---|---|---|---|---|---|---|---|
| **EGgrid** | Electricity generated during a period of time by a grid or mini-grid connected plant | Grid-connected renewable energy generation, fuel switching, or energy efficiency measures in power plants | kWh, MWh | Continuous | Electrical meters at interconnection points can measure power generation | Smart meters to continuously record and report power generation to D-MRV system | Power generation data recorded by smart meters can be uploaded to D-MRV linked to digital billing system so generation data is automatically checked against invoices |
| **EGsinglesys** | Electricity generated by subsystem | Decentralized/ household renewable energy generation | kWh, MWh | Monthly (billing cycle) | Electrical meters, technical specifications, and weather data | Smart meters with SIM card, AI, and weather data | Sampling of technology functionality |
| **Emission factor (fuel)** | $CO_2$ content of fossil fuel | Fuel switching and energy efficiency measures | $CO_2$ per energy or mass/ volume | | – | – | – |
| **Emission factor (plant)** | $CO_2$ content per MWh | Fuel switching and energy efficiency measures | $CO_2$/MWh | | – | – | – |
| **Emission factor (grid)** | $CO_2$ content per MWh | Off-grid or grid-connected energy generation | $CO_2$/MWh | Yes | Electrical meters to report power generation combined with default efficiency or fuel consumption values | Smart meters to automatically report power generation from each plant with linked $CO_2$ factor to automatically determine grid emission factor | Data can be cross-checked with meters at interconnection points in the electrical grid and at the plant level against billing information |
| **Net calorific values** | Energy per mass or volume | Energy generation, fuel switching, energy savings | Megajoules (MJ)/$m^3$ or ton | No (default or specific value) | – | – | – |

**TABLE 9: COMMONLY MONITORED PARAMETERS AND CORRESPONDING DIGITAL TECHNOLOGIES *(cont...)***

| PARAMETER | DESCRIPTION | RELEVANT MITIGATION ACTIONS | DATA UNIT | MONITORING FREQUENCY | MONITORING METHOD/S | DIGITAL TECHNOLOGY | QUALITY CONTROL |
|---|---|---|---|---|---|---|---|
| **Energy saved (thermal)** | Thermal energy saved by activity | Energy savings, fuel switching | MJ, British thermal units | Yes | Purchases receipts or flowrate counters on pipes | Smart meters and digital purchasing/ billing systems | Consumption data from sensors at pipes or similar can be cross-checked with purchases of fuel |
| **Energy saved (electrical)** | Electrical energy saved by the activity | Energy savings, fuel switching | kWh, MWh | Yes | Meters or invoices | Smart meters and digital purchasing/ billing systems | Usage data at meters can be cross-checked with electricity generation or purchases |
| **Number of units** | Number of project systems or users under activity | Household or decentralized systems or products | – | Yes | Sales records or installation certificates | Sales or installation data using smartphones or purchasing software | Cross-checked with wholesale purchase or importation data |
| **Operationality** | Fraction of systems or users in operation | Household or decentralized systems or products | Percent | Yes | Telephonic or in-person surveys | If performance is reported digitally, then operationality is automatically confirmed | Can be cross-checked with in-person inspection or telephonic interview/ mobile phone-based interaction with user |
| **Fuel use** | Fuel switch or project emissions | | Liters or tons | Yes | Purchases receipts or flowrate counters on pipes | Smart meters and digital purchasing/ billing systems | Consumption data from sensors at pipes or similar can be cross-checked with purchases of fuel |
| **Carbon stock** | Tons of carbon dioxide per volume or mass of biomass | Forestry and agriculture projects | $tCO_2/m^3$ or ton | Yes | Satellite data or in-person inspection of biomass | Analyze satellite or drone data with AI to learn how to estimate biomass | Periodic in-person inspection to verify reports from satellite and AI software |

PMIF
PARTNERSHIP FOR MARKET IMPLEMENTATION FACILITY

Administered by
THE WORLD BANK
BRD • IDA | WORLD BANK GROUP

THE NETWORKED CARBON MARKETS INITIATIVE

Climate Warehouse