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IRRI TECHNICAL GUIDELINE

Monitoring, reporting, and verification framework for rice production aligned with Paris Agreement transparency guidelines

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CLIMATE & CLEAN AIR COALITION TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

IRRI

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List of Abbreviations

1M5R – 1 must do, 5 reductions

AMSR-2 – Advanced Microwave Scanning Radiometer-2

AWD – Alternate wetting and drying

BAU – Business-as-usual

BTR – Biennial transparency report

CDM - Clean Development Mechanism

CER - Certified Emission Reductions

CH_4 - Methane

COP - Conference of the Parties

DARD – Department of Agriculture and Rural Development

DCP – Department of Crop Protection

DCPP – District crop production and protection

DNDC – De-Nitrification De-Composition

DSR – Direct seeded rice

EVI – Enhanced Vegetation Index

GHG – Greenhouse gas

GIS – Geographical Information System

INDC – Intended Nationally Determined Contribution

IoT – Internet of Things

IRRI – International Rice Research Institute

IPCC – Intergovernmental Panel on Climate Change

LSWC – Land surface water coverage

LSWI – Land Surface Water Index

MARD – Ministry of Agriculture and Rural Development

MODIS – Moderate Resolution Imaging Spectroradiometer

MRV – Monitoring, Reporting and Verification

MSD – Mid-season drainage

$MtCO_2eq$ – Million tons of carbon dioxide equivalence

NAMA – Nationally Appropriate Mitigation Actions

NDC – Nationally Determined Contribution

NDVI – Normalized Difference Vegetation Index

NGO – Non-government organization

N_2O – Nitrous oxide

PALSAR – Phased Array type L-band Synthetic Aperture Radar

PES – Payment for an Environmental Service

PRISM – Philippine Rice Information System

RIICE – Remote Sensing-based Information and Insurance for Crops in Emerging Economies

SAR – Synthetic Aperture Radar

SECTOR – Source-selective and emission-adjusted GHG calculator tool for cropland

SRI – System of Rice Intensification

SRP – Sustainable Rice Platform

tCO_2eq – Tons of carbon dioxide equivalence

UNFCCC – United Nations Framework Convention on Climate Change

VBA – Visual Basic for Application

VVB – Validation and verification body

1. INTRODUCTION

The Paris Agreement, adopted in December 2015 at the 21st session of the Conference of Parties to the United Nations Framework Convention on Climate Change (UNFCCC), is the first legally binding document for all Parties to address climate change (UNFCCC, 2015). This is reflected in the nationally determined contributions (NDCs) of Parties. Although previous agreements on climate change had been reached, the Paris Agreement marked a new era where all countries will have the same transparency requirements for their greenhouse gas (GHG) emissions reporting from 2020 onwards. These universal requirements provide increased accountability on the steps countries are taking towards implementing the emission reduction goals set forth in their NDCs.

The NDCs are a commitment to reach a certain GHG mitigation goal but these do not provide details on how this goal is to be reached. Prior to the Paris Agreement, the Kyoto Protocol defined several flexible mechanisms including the Clean Development Mechanism (CDM) which allowed mitigation projects in developing countries to generate certified carbon credits – Certified Emission Reductions units (CERs) – that could be traded on the international market (Oberthür & Ott, 1999). A few years later an international framework was established for developing countries' voluntary mitigation action blueprints known as Nationally Appropriate Mitigation Actions (NAMAs) (UNFCCC, 2008). Both of which paved the way for the NDCs.

A central feature of transparency and key to attracting financing for mitigation actions is developing robust and sustainable Monitoring, Reporting and Verification (MRV) systems that follow universally accepted standards which can be adapted to different contexts and ensure reliable and comparable results. This is important to assure international donors of the credibility of the programs and their capacity to deliver real and measurable emission reductions. A robust MRV system reassures donors, markets and the international community that the project delivers real and measurable climate benefits, and facilitates access to emissions trading and results-based finance.

The inclusion of the agriculture sector in international agreements is seen as a means of incentivizing 'climate friendly' production, especially in developing nations. Multiple agricultural GHG mitigation methodologies were approved through rigorous evaluation as acceptable CDMs. Agricultural CDM projects are intended to be both a Payment for an Environmental Service (PES) and an instrument to facilitate sustainable development in developing countries (Haupt and von Lüpke, 2007; Smith and Scherr, 2003). As relatively few CDM projects have come to fruition, especially in agriculture and forestry, NAMAs have taken the forefront in the discussion around climate change action and how to meet NDCs. This is evidenced by the fact that 40% of the countries including cropland management in their NDCs at the 21st Conference of the Parties (COP21) specifically mention rice management (FAO, 2016) and more recently during COP25 where 48% of the countries negotiating included some mention of rice in their agricultural NDCs[1], including China, Bangladesh, and Vietnam that collectively account for 42% of the rice produced globally.

Several major rice producing and consuming countries in Asia have joined the international community in ratifying the Paris Agreement and its Action Plan whereby they have committed to reducing GHG emissions in rice by 2030 relative to the business-as-usual (BAU) levels. For example, Vietnam plans to target the rice sub-sector by converting 1.2 million hectares of rice to low-emission production with unconditional financing, whereas Thailand's economy-wide commitments include rice sector actions. In the Biennial Update Report for UNFCCC, India recognizes that rice is an important source of methane and they mention the System of Rice Intensification (SRI) and Direct Seeded Rice (DSR) as effective methods to reduce emissions from rice but do not indicate specific actions or targets in the rice sector (MoEFCC, 2018). Paddy rice cultivation contributes 55% (27.86 m tCO_{2eq}) and 48% (42.56 m tCO_{2eq}) of the total agriculture emissions in Thailand and Vietnam, respectively (MNRE, 2018; GoV, 2017). Myanmar has also mentioned potential actions for mitigation in the rice sector in their intended NDCs (INDCs) but they have yet to submit a biennial transparency report for the Paris Agreement. The Thai Rice NAMA is an example of bilateral funding which aims to achieve 1.66 million tons carbon dioxide equivalent ($MtCO_2e$) reduction of emissions from rice production over 5 years.

The agriculture sector in Vietnam contributes a significant proportion of the nation's GHG emissions with rice production responsible for 44.61 $MtCO_2e$ or 18% of total national GHG emissions. This amount is one and a half times more than the entire transportation sector in Vietnam including air, road, rail, rivers and seaways. The current mitigation measures for agriculture listed in Vietnam's technical NDC reports are heavily dependent upon mitigation from the rice sector with more than a quarter of the measures directly relating to rice (in bold and italics): biogas, ***agricultural residues***, ***alternate wetting and drying***, ***mid-season drainage***, biochar, ***integrated management of rice***, integrated management of crops, ***substitution of urea fertilizer***, cattle diets, improved aquaculture, improved waste in aquaculture, food processing, and waste treatment and irrigation in coffee production (Carbonari, 2019). All of Vietnam's unconditional mitigation targets involve the rice sector and 38% of mitigation from conditional funding sources is earmarked for actions in the rice sector.

Although Vietnam and Thailand have strong supporting legal frameworks and enabling political environments, an MRV has yet to be developed at the national levels and for the different sectors.

[1] https://www.climatechangenews.com/2019/12/07/can-grow-climate-friendly-rice/

This could be explained by the fact that the capacity to implement MRV at the national level in general, and in the different agriculture sectors, especially in the measurement component, is weak. According to reports, there are insufficient facilities, equipment, and human resources to satisfy the requirements of MRV tasks, especially in ensuring transparency and compliance to the UNFCCC MRV Framework (Trung, et al. 2017).

There are two objectives of this paper:

1) Analyze the current internationally accepted MRV methodologies for reduced methane emissions in rice production and showcase tools used in MRV tailored to different user purposes (i.e., Government NDCs, NGO impact assessments, carbon credits);
2) Provide a suite of tools and a methodology adapted to monitor NDC progress at a national level

This critical review takes a novel approach to assessing the existing MRV methodology and tools and provides expert-based recommendations for adjusted MRV standards that adapt current guidelines as a promising way forward to deliver transparency in meeting the NDCs. Additionally, this is a timely proposition given the necessity to define an MRV framework for NAMAs for the rice sector. We are recommending a multi-pronged approach using several tools that can support and validate each other to achieve a robust mechanism for MRV estimations in the rice sector. Examples from Vietnam will be used as a case study given their government's strong commitment to mitigation in the rice sector.

The reason flooded rice fields are a large source of methane emissions (second only to ruminant livestock) is because of the anaerobic digestion by methanogenic bacteria that thrive well in flooded paddy rice fields. The periodic aeration of the soil, also known as alternate wetting and drying[2] (AWD), inhibits methane-producing bacteria which can reduce methane emissions by 48% on average (IPCC 2006). The annual amount of methane (CH_4) and nitrous oxide (N_2O) emitted from a given area of rice is a function of: 1) the number and duration of crops grown, 2) water regimes before and during cultivation period, and 3) organic and inorganic soil amendments (Neue and Sass, 1994; Minami, 1995). Soil type, temperature, and type of rice cultivar also affect CH_4 emissions. To effectively measure, report, and verify emissions, the above factors need to be collected and assessed on a seasonal or annual basis. The following methods and tools currently exist or are in development for use in the MRV process for reduced emissions in rice production. See Table 1 for

[2] In this context "AWD" is a term that refers to "more than one aeration" between the times *after the planting of rice* and *2 weeks before harvest*. The term AWD here is interchangeable with the terms intermittent flooding, intermittent drainage, multiple aeration, controlled irrigation, and is the main mitigation action in the management packages System Rice Intensification (SRI), Sustainable Rice Platform (SRP), and Direct Seeded Rice (DSR).

how these tools can be used to support different components of planning, financing, measuring, monitoring, reporting, and verifying reduced emissions in rice production.

Internationally accepted MRV methodologies for rice:

- American Carbon Registry: Rice Management Systems Methodology[3] – DNDC process-based model. Accepted by voluntary carbon registries as Improved Agriculture Land Management Methodology. MRV methodology to guarantee that ***change*** took place which resulted in reduced emissions
- CDM Methodology AMS.III.AU: Methane emission reduction by adjusted water management practice in rice cultivation – IPCC equation-based model. Accepted by non-voluntary (e.g., UNFCCC) and voluntary carbon registries (e.g., Gold Standard, Verra). MRV methodology to guarantee that ***change*** took place which resulted in reduced emissions.
- Sustainable Rice Platform Assurance Scheme* – Not accepted for issuing certification of emission reduction. MRV methodology to guarantee specific management actions occurred.

*not capable of accounting for reduced emissions because no baseline conditions are established from which change can be measured

MRV support and Greenhouse gas calculation tools[4]:

- Analog and digital sensors – AWD tube (in-field water level pani pipes), *AutoMon* (automated irrigation scheduler and digital in-field water level monitor), soil moisture sensors
- Appraisal – individual farmer/service provider surveys or reports; digital reporting app
- Closed chamber gas measurements – use to establish IPCC Tier 2 emission factors for more accurate regional estimations/calculations
- *CF-Rice*: Carbon Footprint calculation tool for on-farm and off-farm emissions – includes emissions along the entire supply chain in addition to direct and in-direct farm-level emissions
- Remote sensing/satellite – planning tool, monitoring, reporting, and verification
- *RiceMo*: Statistical reporting – aggregate regional government polling/reporting
- *SECTOR*: GHG calculator for on-farm emissions – calculation tool which can be used in combination with suitability maps, appraisal and/or statistical reporting, and satellite data to calculate GHG emissions of a project area

Other helpful tools:

- *COMPARE*: Cost-benefit analysis tool – project planning, budgeting, and targeting tool
- *MapAWD*: Suitability maps – project planning and area targeting tool

[3] Currently, only rice fields in the state of California are covered by this methodology. However, it is the explicit intent of this methodology to be expanded to other regions in the US and outside the US.

[4] Tools in italics represent tools developed by the International Rice Research Institute

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</table>

Tools tailored to rice (contd.)	Planning	GHG calculation	Establish baseline/ project emission	MRV of emission reduction	Certification of emission reduction	Ntl / Rgnl	Project	Field	Relative Cost	Development Stage
COMPARE - Cost-Benefit Analysis	✔	✔				✔	✔	✔	$	V1.1
MapAWD – Suitability maps Nelson et al. 2015	✔					✔	✔		$$	V1.2
RiceMo - Statistical reporting		✔	✔	✔		✔	✔		$-$$$	pilot
Remote sensing/Satellite	✔	✔	✔	✔		✔	✔	✔	$$$$	R&D
SECTOR - GHG calculator for cultivation-related emissions - Wassman et al. 2019	✔	✔	✔	✔		✔	✔*	✔*	$	V2.1 *Requires Tier 2 emission factors
Soil moisture sensor		✔	✔	✔				✔	$$$	Available
Third-party verification	✔		✔	V only	✔		✔	✔	$$$$	N/A

2. Project Planning

Pre-requisite conditions

The following section details the conditions that are necessary to effectively apply AWD to achieve emission reductions and the tools that can be used to establish the project area and mitigation potential.

Cropping conditions and bio-physical conditions:

1. Rice cultivation must be irrigated throughout the growing season and pre-season (upland, rainfed lowland, and deep water systems are not eligible).
2. Fields are flooded for extended periods of time – continuous flooding conditions after the rice is planted up until two weeks before harvest.

   Tools to assist suitability planning:
   - *MapAWD: Climatic suitability maps* – Mapping the planted area of rice based on statistical data, rice cropping calendars and remote sensing images. Climatic factors including rainfall, potential evapotranspiration and soil percolation rate of rice land based on soil type are used to assess the water balance seasonally (see Figure 1).

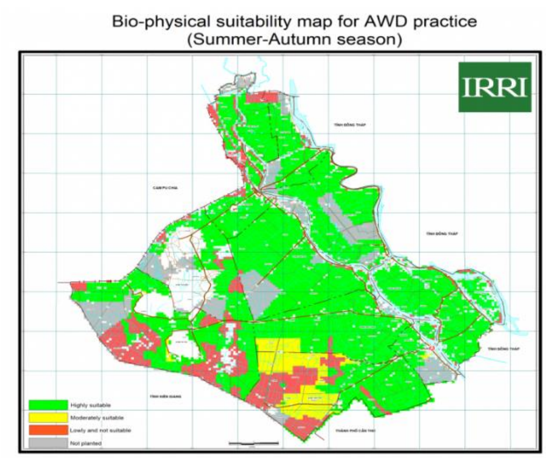

Figure 1 Example of MapAWD for An Giang Province showing the seasonally suitable area for AWD in green

   - *ISRIC-WISE:* soil pH and soil organic carbon can be accessed from property database or national data
   - *Rice Almanac or Harvest Choice*: agro-ecological zones climate data

Adoption capacity conditions:

1. The project area is equipped with controlled irrigation and drainage facilities to maintain water management schedule.
2. Training and technical support are provided and documented in a verifiable manner before and during the cropping season to deliver information on appropriate management[5]. For example,

[5] Field preparation conditions for pre-season irrigation and organic amendment incorporation, crop establishment, in-season irrigation and drainage regime to avoid any yield losses, efficient use of fertilizer (with expert guidance using

see training manual here in Vietnamese.

Tool to assist planning:

- *Adoption capacity maps*: Five influencing factors taken into account, including topography, canal irrigation infrastructure, drainage capability, training capacity/farmer awareness of controlled irrigation, and cooperative authority. A cumulative score is provided at the selected administrative unit (i.e., village, county, district, etc) which are then georeferenced to create a map (Nelson et al., 2021).

The climatic suitability map and the adoption capacity map are then combined to create an overall AWD suitability map. The final combined map is then verified and adjusted through a participatory feedback process including relevant stakeholders (i.e., government, researchers, farmer groups, etc). For more detailed information on this process, please see Nelson et al., 2021.

Tools to establish project plan

Cost-benefit analysis

- The cost-benefit analysis tool enables users to input the targeted project area calculated from the suitability maps to compare the economic and environmental benefits of conversion to low-emission rice under different technology improvements and project cost scenarios (soft skills training vs. hard infrastructure) to aid NDC decision making and private sector investment.

  Tool to assist planning:

  - *COMPARE*: Financial results are provided for 8 different rice management regimes including 1) traditional; 2) AWD; 3) mid-season drainage; 4) Efficient fertilizer management; 5) straw management; 6) 1 Must Do, 5 Reductions (1M5R); 7) SRI; and 8) SRP. Results may be compared at the landscape scale for: Project costs, Revenue, Cost of carbon abatement, Internal Rate of Return, Net Present Value, Net Future Value, Annual annuity, Breakeven point, Benefit cost ratio, etc. Environmental results are provided in the form of total carbon abatement, abatement per hectare, water savings, and reduced air pollution from halting straw burning.

3. Establishing baselines and target indicators

According to the standardized methodologies for issuing certified emission reduction credits for practicing AWD in rice production, the following data are required for categorizing similar field groups and defining baseline conditions. These parameters and methods should be used for

scientific knowledge of the site-specific nutrient needs, a leaf color chart or photo sensor or testing stripes), and post-harvest residue disposal.

collecting baseline and project emission measurements (UNFCCC 2014). Areas with different baseline conditions will need to be marked as such to properly measure, monitor and report the emissions, regardless of whether the goal is to achieve the NDCs or to earn carbon credits. Areas should be delineated according to the classification of specific patterns of cultivation conditions as defined below. The area(s) subject to MRV will be grouped according to similar cultivation patterns. All fields with the same cultivation pattern form one group and each group is then subjected to a multi-pronged MRV approach depending on the project purpose. For example, projects that intend to produce carbon credits will need to follow the guidelines for accreditation strictly while publicly funded projects can be more flexible in the approach. We make suggestions here to justify applying for deviation from the current MRV guidelines for carbon accreditation as they may be financially unviable in a small-holder context.

Table 2 Parameters for defining cultivation patterns

Nr.	Parameter	Type	Values/categories	Source/Method	Tools/Methods
1	Water regime pre-season	Dynamic	Flooded (>30d) Short drainage (<180d) Long drainage (>180d)	Baseline: Appraisal Project: Monitoring Appraisal	Survey / Report App *RiceMo* *AutoMon* Remote sensing/Satellite - Change detection approach
2	Water regime on-season	Dynamic[6]	Continuous flooding Single drainage Multiple drainage (AWD)	Baseline: Appraisal and statistical surveys / default (Tier 2 preferably) emission factors Project: Monitoring Appraisal and statistical surveys, satellite data, moisture/water flow meters	Survey / Report App *RiceMo* *AutoMon* Remote sensing/Satellite - Change detection approach
3	Organic amendment	Dynamic	Straw short incorporation (<30d) Green manure Straw long incorporation (>30d)	Baseline: Appraisal Project: Monitoring Appraisal	Report App Remote sensing

[6] Dynamic conditions are those that are connected to the management practice of a field, thus can change over time (no matter whether intended by the project activity or due to other reasons) and shall be monitored in the project fields. Static conditions are site-specific parameters that characterize a soil and do not (relevantly) change over time and thus do in principle only have to be determined once for a project and the corresponding fields.

			Farmyard manure		
			Compost		
			No organic amendments		
4	Soil pH	Static	<4.5	ISRIC-WISE soil property database or national data	*MapAWD*
			4.5-5.5		
			>5.5		
5	Soil organic carbon	Static	<1%	ISRIC-WISE soil property database or national data	*MapAWD*
			1%-3%		
			>3%		
6	Climate	Static	[AEZ]	Rice Almanac, Harvest Choice	*MapAWD*

Source: Adapted from UNFCCC Clean Development Mechanism methodology: AMS.III.AU (2014)

Given the necessity to include the above parameters in the field group categorization for monitoring and data measurement purposes, we recommend incorporating this information into the suitability planning maps to define the targeted field groups and cultivation boundaries in an area to assist with planning and monitoring. For example, a relatively homogenous area will have fewer boundaries and therefore reduce baseline and MRV costs while still maintaining an acceptable level of accuracy needed for estimating GHG emissions. Areas representing a high level of heterogeneity in the above parameters are more likely to incur higher costs to effectively monitor more groups composed of fewer farms per group. The sections on farmer appraisal surveys and government statistical reporting outline the methodology for collecting the data needed to define the groups, project boundaries, and baseline conditions.

Baseline

Depending on the outcome purpose sought with the MRV, the approach and rigor will differ. If the purpose of MRV is to show that a specific action happened but the resulting change from that action is not the focus, there may be no need to establish a baseline. This would be the case of MRV for Sustainable Rice Platform (SRP) projects. When measuring a change that results in emission reduction, as is necessary for carbon accreditation and NDCs, it is necessary to determine the baseline parameters for establishing the starting point within a specifically defined area (i.e., district, province, region, etc). Establishing the baseline requires measuring, reporting and validating the current situation so, naturally, the same MRV methodologies apply. These include collecting data through in-field measurements and through reported information (i.e., appraisal surveys / logbooks, and statistical reports). For the purpose of NDCs, the in-field closed chamber gas measurements are important to establish Tier 2 emission factors. If Tier 2 emission factors have already been established for the region, these are not necessary to measure again. Collecting data on current water management is a critical point to establishing a sound baseline and cannot be overlooked for the NDCs. The only way to know that emissions are lower than a business-as-usual (BAU) baseline scenario is to have a firm understanding and supporting data of the current way of doing things, or the "usual business". The best options for establishing the BAU baseline for the NDCs would be to use a statistical reporting system, such as RiceMo, or to use remote sensing/satellite technology supported by ground truthed data at a broad scale (i.e., surveys). Although the use of satellite imagery to detect water management in rice production is in its infancy, there is promise that this technology will continue to advance and play a role in MRV in the future.

Indicators to track progress

Developing innovative indicators to track and communicate progress of emissions reduction in rice is critical to ensuring transparency and offers an opportunity to develop cost effective methods for MRV. Transparency under the Paris Agreement refers to the reporting of information by a Party in its biennial transparency report (BTR) (including information on the GHG inventory, the accounting approach(es) selected and the indicators used for tracking progress and support provided and received) (UNFCCC, 2019). The provision of clear and understandable data and information in the BTR and the NDC helps to ensure transparency. Clear indicators are central to this process and are specifically manifested in provisions to offer flexibility to developing country Parties. The NDCs allow for diverse actions, and discretion regarding which relevant indicators countries may use to track progress in meeting their goals (UNFCCC, 2019).

Reducing emissions in rice production requires changes in individual behavior. In the absence of direct subsidies or incentives, this change will likely happen through training programs. However, training isn't guaranteed to lead to compliance. Relatively low cost research to follow-up with trained farmers and establish an average level of compliance could achieve the goal of developing a proxy for emission reduction. This would require a power analysis to determine the minimum sample size of farmers that would need to be surveyed to establish the average compliance rate that is statistically relevant. This would be a relatively low cost option given that training is in-person and recording basic information from attendees would not incur additional costs since the training already involves an expense to achieve the desired reduction. At minimum, basic information such as size of land, number of seasons, and yield should be collected so this can be regressed against their compliance to understand if some segments of farmers are more or less likely to comply. This information can be used to improve the proxy estimates if broad scale summary statistics of rice production can be expressed as a distribution on land size, seasons, and yield. Since there may be reduced compliance over time, it would be important to collect data from trained farmers for several seasons and build these results into the estimates to improve the accuracy of the indicator. In the case that multiple organizations offer different training programs which may result in different levels of compliance, this should be taken into account during the data collection process.

Alternatively, in countries where irrigation is largely a service provision that serves multiple farms collectively, the kilowatts of energy used to provide irrigation services could potentially also be used as an indicator when volumetric measurement of water isn't available. This would require initial research to establish the average kilowatts of energy per hectare for continuously flooding fields compared to the average kilowatts per hectare for alternating wetting and drying, controlling for variables such as the pump size, canal size, distance to fields from the source, etc. It is likely that a minimum service area would need to be established to determine financial viability of using this indicator unless service providers are registered as identifiable irrigation companies and the data are accessible via the electricity company so the field data does not need to be collected seasonally.

4. In-field measurements

Closed chamber gas measurements

One option for establishing a baseline is through the use of context-specific emission factors, also known as IPCC Tier 2 factors. In-field gas measurements should be taken for areas characterized by different bio-physical traits, as defined by parameters 4, 5, and 6 from Table 2. In-field measurements on a large scale (Tier 3), although highly accurate for the specific conditions, are also expensive and are not a viable economic option, especially not in developing country contexts with small-holder farmers. Tier 2 factors provide more accurate data than Tier 1, and for this reason, we recommend establishing Tier 2 factors by collecting data using closed-chamber methods that are representative of local conditions. These values can then be used to determine baseline emissions and to estimate the change in emissions from the actions funded to achieve the NDCs based on data of farmer practices collected using appraisal surveys or statistical reporting methods.

Justification to apply for deviation to AMS.III.AU for in-field measurements for carbon credit projects: According to the UNFCCC MRV guidelines for methane emission reduction by adjusted water management practice in rice cultivation, in-field measurement for three reference fields per cultivation pattern group are necessary to establish the baseline (control) and three project reference fields (intervention). For establishing change over time as needed for MRV, an acceptable adjustment would be to limit the need for field measurements to areas characterized by different bio-physical traits (i.e., parameters 4, 5, and 6 from Table 2) rather than require reference fields for changes in management, which can be estimated using IPCC equations. There is also no need for a control field for closed-chamber measurements because the project emissions will be calculated using IPCC equations.

The links below provide an overview of the protocol for the closed chamber method with various links to other protocols:

https://samples.ccafs.cgiar.org/measurement-methods/chapter-4-quantifying-greenhouse-gas-emissions-from-managed-and-natural-soils/

https://globalresearchalliance.org/library/guidelines-for-measuring-ch4-and-n2o-emissions-from-rice-paddies-by-manually-operated-closed-chamber-method/

Water level indicators

A practical way to measure and monitor the water depth in the field to safely implement AWD and to assist accurate recording of water depth throughout the growing cycle is by using a field water tube, or observation well or 'pani pipe' (see Figure 2a and 2b). After irrigation, the water depth in the field will gradually decrease. The water should never go lower than -15cm below the surface of the soil (shallower is acceptable). Once the water level has dropped below the soil surface for a few days (not to exceed the -15cm limit), irrigation may be applied to re-flood the field to a depth of about +5 cm. Farmers can record the water level according to a particular schedule that can be used at the end of the season to both assist with the estimation of GHG emissions by providing accurate feedback on water management for use with the GHG calculator, SECTOR, and these measurements can also be used for the validation/verification process to guarantee specific cultivation processes took place.

Figure 2a (left) shows the perforated AWD tube and figure 2b (right) shows how it should be used in the field to measure the water level using a ruler/measuring tape. Source: www.irri.org

AutoMon

In collaboration with national partners, IRRI has developed an internet of things (IoT) based irrigation advisory service called "AutoMon" that entails efficient water management, continuous monitoring, reporting and verification of water management practices, and a multi-stakeholder interface (Figure 3). The AutoMon is targeted to offer a system-level solution (Figure 3 b) for efficient management of irrigation water that will help the various stakeholders perform their responsibilities more efficiently and promptly while bringing all-important transparency to water governance. The AutoMon consists of various components, including characterization of landscape, sensor nodes, gateway, backend data handling, user interference, maintenance, and troubleshooting. The AutoMon based irrigation advisory is using both GSM and radio frequency as a mode of data transmission. The user interface has been customized based on stakeholder roles and interests. The information is shared in the local language. Given this automized process, the possibility for human error or manipulation in the measuring or recording process is minimized which makes the output (Figure 4) an important tool for validation/verification.

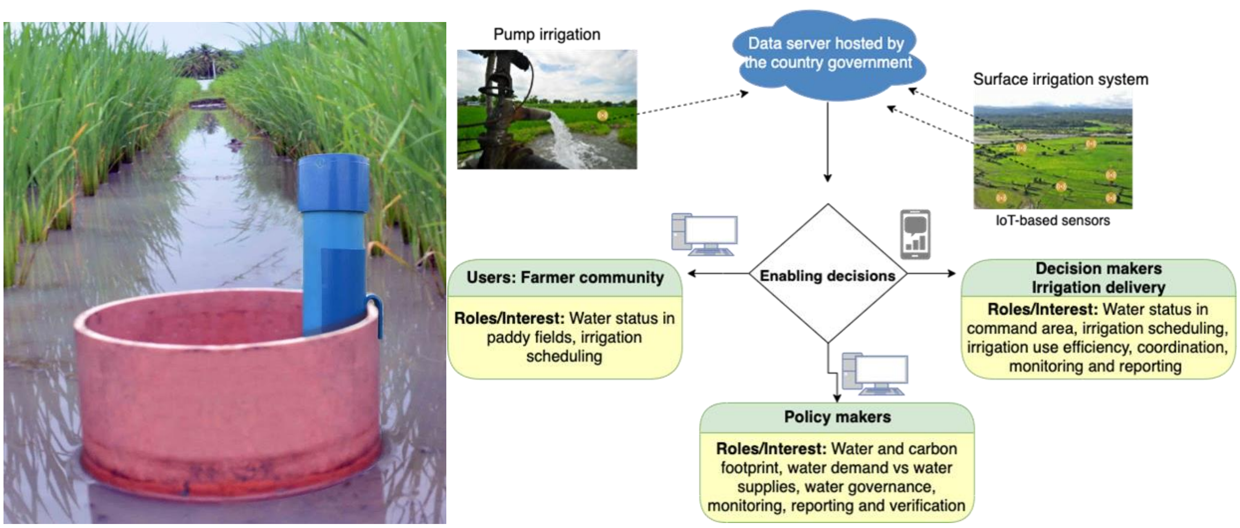

Figure 3a (left) Automated water level sensor attached to AWD shown in flooded rice field. Figure 3b (right) shows the IoT schematic of how AutoMon can be used for decision making across different stakeholder groups. Source: https://www.irri.org/automonph

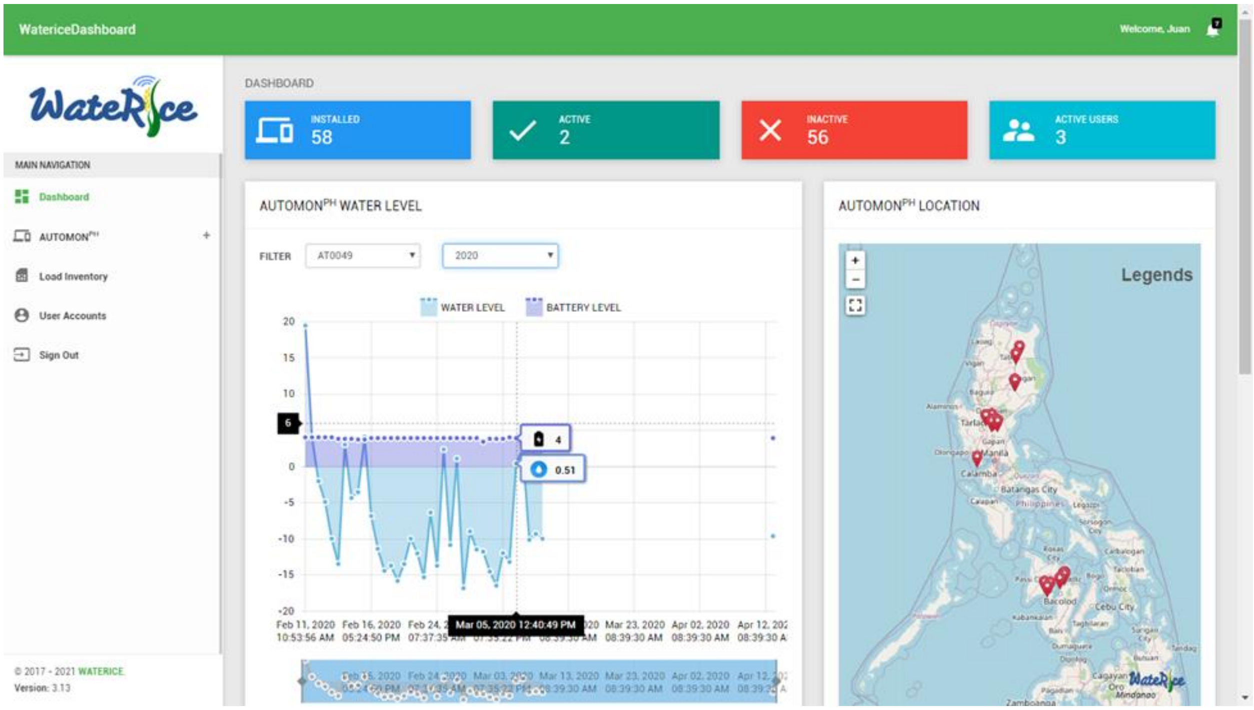

Figure 4 shows the recorded water level output of Automon over a rice growing season.
Source: https://www.irri.org/automonph

Soil moisture sensors

Similar to the water level indicators, soil moisture sensors can be used to detect the degree of moisture in soil. An example from Carrijo et al. (2018) measures the soil volumetric water content at 0 to –15 cm depth throughout the season using soil sensors (Decagon Devices 10HS, Inc., Pullman, WA) connected to data loggers used for recording purposes. There are many other commercial moisture sensors available on the market. In general, most of these sensors work very well when soil moisture depletes below the field capacity, however, their performance can be inconsistent between saturation to 10-15 kPa (recommended soil water tension for implementing AWD). The output can be used for validation/verification as well.

Lovell (2019) uses soil sensors to triangulate data from satellite imagery and provides some basic directions for soil moisture meter installation:

- Install a series of soil moisture meters in strategic locations during specific set seasons (dry seasons are best as excessive rainfall will affect the ability to practice AWD)
- Install moisture meters in the different major soil types in the region
- Install moisture meters in known AWD fields and in non-AWD fields with a minimum of three replications per site

- Install soil moisture meters at least 10 meters away from the edge of the rice fields to account for edge effects of watering regimes in the AWD and non-AWD fields.
- Use moisture meters fitted with a solar panel to power the sensor in itself as well as the remote relay apparatus.
- Attach air and humidity gauges (if possible and feasible) to the meters to understand climatic conditions and effects.
- Soil moisture meter data remotely relayed on an hourly basis
- Calibration of soil moisture percentage occurred throughout the soil moisture meter tenure.

Given that all of these in-field measurements collect data that are specific to individual field conditions, these methodologies for MRV may be best suited to large farms, private investment projects, or research rather than MRV for NDCs, especially in developing country contexts where most farmers have small plots of less than 2ha, as the costs will be relatively high compared to randomized appraisal, statistical reporting, and satellite imagery. However, used on a large scale for triangulation of data, these methods could be applied across a randomized sample of fields within a project area to combine the data with statistical reporting and farmer appraisal surveys or with satellite imagery to determine the margin of error that is likely to occur through less costly, and potentially less accurate, MRV systems so the level of uncertainty can be adjusted for error.

5. Appraisal

In some cases, such as the case of carbon credit projects, it may be necessary to survey each individual farmer prior to enrollment in the project, as well as, some farmers outside the project in order to qualify for eligibility, additionality, and to establish the baseline. For national efforts to reduce emissions under NDCs this is not economically feasible and it will be important to sample randomly across the targeted population and to work together with government extension officers (see section 6) to establish a representative analysis of current conditions for the BAU baseline. It is crucial to define tentative group boundaries based on expert knowledge of local conditions and practices which can then be supported by representative sampling of farmers through surveys and/or self-reported logbooks. A sample of a farmer survey including all the questions necessary to collect the data for calculating ex-ante estimations of farm-level GHG emissions is included in the Appendix. This is the same data that should be collected in farmer logbooks. Digitizing this process by making the reporting accessible by mobile app will reduce costs of administering and collecting paper reports, and entering the data manually.

Currently, individual farmer surveys and self-reported logbooks are the only accepted method for reporting[7] (SRP assurance scheme and UNFCCC MRV methodology for emission reduction). However, self-reporting and survey responses may be subject to response bias (or survey bias) wherein the participants trained to implement AWD and trained in how to properly fill out the logbook, may inaccurately represent the activities that took place to be a good project participant or to provide socially desirable responses rather than truthfully describing their seasonal cultivation practices. There are multiple approaches to reduce this bias, including refraining from asking respondents the dichotomous question "Did you practice AWD?", and instead asking them to report on their irrigation schedule by having them mark the times when they irrigated and when irrigation stopped. Depending on the type of soil, the number of days between irrigation events can then reveal if the field reached a dry-down period and how many times this occurred over the season. Asking respondents to select the option that best represents their practice from graphical images showing continuous flooding, single aeration, and multiple aeration, is another way to ask the question (see survey in appendix for example). Importantly, testing the survey for internal consistency by including multiple questions formulated differently but intended to achieve the same response will improve reliability and validity of the results. Additionally, the estimated mean survey results combined with at least one other MRV method, such as in-field measurements (water level sensors, or soil moisture sensors), satellite imagery, or statistical reporting, can provide triangulation of data and serves as a robust check.

RiceReport App

IRRI is currently developing a mobile application version of the farmer reporting system to simplify the process of data collection and data entry to save time and money and to reduce potential for human error. Additionally, this system can also function as a two-way feedback mechanism to send reminders and other information to participating farmers and the system could be connected to in-field measurements such as AutoMon for data triangulation. Both paper surveys/logbooks and digitally recorded information can be used in the validation/verification process by the auditor.

Sampling

Both the SRP assurance scheme and the UNFCCC MRV methodology outline acceptable sampling procedures. It is best practice to follow established guidelines from accepted MRV methodologies or use a power analysis calculator to determine a minimum sample size in order to have sufficient statistical power to detect a change from the baseline (in the case of emission reduction verification). For carbon credit projects, the UNFCCC MRV methodology requires all farmers to submit logbooks

[7] Reporting closed chamber gas measurements are also acceptable for the UNFCCC MRV methodology but this is economically infeasible outside of research purposes

of their cultivation practices of which a sample of these logbooks is analyzed for monitoring and reporting purposes. An approved third party validation/verification body (VVB) then independently analyzes a sample of the farmer logbooks and if the results are within an acceptable margin of error, these are accepted for validation/verification of the practices and emission reduction. If the margin of error is unacceptable, all farmer logbooks must be analyzed to validate/verify the practices and emission reduction.

Calculation

SECTOR

For ex-ante estimation of emission reductions, the MRV methodology should estimate seasonal emissions using national data (Tier 2) or IPCC Tier 1 default values for emission and scaling factors[8]. The recent 2019 refinement to the IPCC guidelines (2006) includes the equations for calculating emissions from rice production including the adjusted daily emission factor, country-specific emission factors and scaling factors for water regime during and before cultivation period and organic amendments. We recommend using the Source-selective and Emission-adjusted GHG Calculator (SECTOR) tool for Cropland which is intended for use as an add-on to field measurements, for GHG calculation at national/sectorial scale and the results can be used for monitoring and reporting purposes (Wassmann et al., 2019). This tool can also be used for project planning and establishing baseline conditions based on farmer input of cultivation practices using default emission and scaling factors. There are also many other tools available for estimating GHGs emissions (e.g., Cool Farm Tool, Ex-ACT, Mitigation Options Tool, etc).

CF-Rice

CF-Rice is a carbon footprint calculator for the entire rice value chain. This differs from SECTOR by accounting for emissions during harvest and postharvest activities including processing, handling, storage, transportation, and accounting for the emissions from food losses and waste. Similarly to SECTOR, the data for on-farm cultivation practices is collected from farmers and harvest/postharvest practices are collected from service providers, rice traders, millers, or rice retailers to analyze emissions data for a batch of rice. This tool developed by IRRI calculates ex-ante emission estimations from farm-to-shelf that are useful for project planning, establishing baseline emissions, measuring, and reporting.

The aggregate results from SECTOR and CF-Rice could potentially be used during the verification process to show the amount of emission reduction that occurred from which processes but this has

[8] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_05_Ch5_Cropland.pdf

yet to be formally accepted as a verification mechanism. The underlying calculation equations will be built into the RiceReport App to produce an output that shows not only the cultivation practices but also the resulting seasonal GHG emissions based on these practices. There are other carbon footprint calculators that incorporate food losses and waste along the value chain into the GHG estimations (e.g., ACE Calculator) but CF-Rice offers the most comprehensive tool tailored specifically to rice.

6. Government Statistical Reporting

Most government statistical reporting includes agricultural statistics that are collected on an annual basis and include cropping area and yield statistics. These statistics are collated at the province level from data collected at the village and district level. A well developed and standardized statistical reporting system is a prerequisite for this type of MRV to be successful. Vietnam is well-known for its systematic reporting that is recorded on a publicly available database. Since 2010, the Ministry of Agriculture and Rural Development of Vietnam has been implementing a more detailed reporting system to monitor crop production progress in all provinces. This reporting system frequently records very detailed field observations using an existing hierarchical network, which includes thousands of reporters from provinces, districts and communes. Fundamental information on planted area, established date, variety, development stage, applied technologies, pest and disease, harvested area, yield, etc. of crops are reported to the Department of Crop Production (DCP) frequently. Depending on crops and type of information and agro-ecology, the length of the reporting interval can be weekly, monthly or seasonally. In the cases of pest and disease outbreaks or natural hazards, the reporting interval can be adjusted accordingly. For rice, production progress is reported weekly due to the short rice season (90-120 days), complicated cropping systems and planting calendar across the country.

In implementation, agricultural officials from communes observe field progress and report to the district crop production and protection (DCPP) station. At this level, field observation can be reported using a pre-printed form, email, telephone or through face to face meetings. The district officials summarize communal data and then reports to the provincial DCPP office normally via email. In turn, provincial officials report summarized data of the province to DCP. Finally, the DCP use this reported data to inform MARD’s policy makers and the National General Statistical Office.

Although this reporting system currently works very well in summarizing general production progress of provinces for regional and national planning, there are several limitations, especially in verification and development of local responses. First, because the reported data is summarized and not geo-referenced, managers and policymakers at district and higher levels may not be able to verify information by comparing with other data sources (e.g. satellite images). Second, it is difficult to analyze situations and make timely responsive decisions, which have to be based on spatial distribution of crop, crop variety, development stage, topographic feature and spatial occurrence of impact factors (e.g. drought, flood and brown planthopper outbreak). Third, operation of the system is time and labor consuming as it requires officials to do summarizing at every level. Even so, the system is the foundation for development of a more concrete system for measurement, monitoring, reporting and verification of production activities, including implementation of mitigation options.

RiceMo

Starting from 2019, IRRI has seen the governmental statistical system as an entry point to develop a comprehensive national MRV system for low emission rice production. IRRI has been working closely with DCP and Department of Agriculture and Rural Development (DARD) of Can Tho City to develop and pilot the RiceMo tool. The win-win objectives of this work is to: 1) help DCP to improve their existing reporting system by integrating functions for automatic summarizing, generating thematic maps and reports, and systematically connecting local to regional and national database, and 2) to monitor and verify implementation of low emission rice practices recommended by the NDCs (i.e. Alternate Wetting and Drying-AWD, Mid Season Drainage -MSD) and by MARD (i.e. One must do-five reductions, three gains-three reductions).

The tool is intended to be "simple" in formulation, as user-friendly as possible, and requires a minimum IT knowledge of non-expert users. The tool is provided in an Excel environment embedded with a special interface and functions that are developed using Visual Basic for Application (VBA) language and open-source GIS library, a plug-in component that allows the display of spatially distributed variables. The tool is currently being tested by district officials in An Giang province. It is expected to be piloted in the next rice season in the province.

The statistical reporting enables seasonal updates that can be used for MRV purposes in conjunction with the Source-selective and Emission-adjusted GHG Calculator (SECTOR) tool for Cropland to calculate emissions at different scales (commune/district/province/national) based on farming practices. (Wassmann et al., 2019).

7. Satellite data

Promising developments for MRV include the use of remote sensing technology to map and monitor rice areas and estimate GHG and AWD adoption (Table 3). The use of satellite data, specifically, Synthetic Aperture Radar (SAR), has been demonstrated to accurately map rice areas in the tropics where cloud cover is pervasive (Lam-Dao, 2009; Nelson et al., 2014). A system for mapping and monitoring rice areas using Sentinel 1A and a rule-based algorithm (Nelson et al., 2014) has been operationalized in the Philippines (Philippine Rice Information System or PRISM: https://prism.philrice.gov.ph/). A similar system has been setup in Vietnam and Cambodia and used in crop insurance (Remote Sensing-based Information and Insurance for Crops in Emerging Economies or RIICE: https://www.riice.org/). SAR has advantages for mapping rice in the tropics. L-Band data is needed to detect dry down periods in rice (the longer L-band waves can penetrate much deeper into vegetation); however, the temporal resolution is weak. The launch of ALOS-4, NISAR and Tandem-L in the next few years, will allow more frequent monitoring with L-band SAR.

Using satellite imagery to determine water management in rice production, and to monitor changes in water management over time for use in measuring, reporting, and verifying emission reduction is still in the early stages of testing for accuracy. Multiple issues including the frequency of satellite pass overs, spatial resolution, cloud coverage in tropical regions (a problem for optical imagery), and canopy cover of the field complicate the use of satellite technology. Table 3 shows a literature review of studies that used satellite technology to map rice growing regions using water detection to define cultivation area, and to observe flooding frequency and changes in water management during a growing season. The table includes the results and limitations of these studies, as well as, the GHG estimation methods to assess emissions from rice cultivation, including biogeochemical models (DNDC) and default guidelines (IPCC) that can be combined with the satellite data to estimate GHG emissions showing how an MRV system using satellite technology would operate. Few studies have addressed the inundation/non-inundation classification of soils covered by vegetation without sacrificing the spatial resolution (Arai et al., 2018). Studies show low SAR backscattering coefficients in inundated paddies during the early tillering stage, i.e., 0–20 days after sowing (Inoue et al., 2002, Lam-Dao et al., 2009). Very few studies, however, detected inundation/non-inundation during the later growing stages due to the saturation of the backscattering intensity in the rice plant canopy, which does not allow some SAR bands to penetrate the canopy and reach the soil surface (Lam-Dao et al., 2009). A recent study by Arai et al. (2018) demonstrated the ability to distinguish between inundated and non-inundated paddy soils even when they were covered by large rice plants by employing the PALSAR-2 L-band data which have longer waves that can penetrate deeper into vegetation. Further research needs to be conducted.

Given the complex nature of calculating emissions from satellite data using biogeochemical models in developing country contexts, applying scaling factors from IPCC guidelines to a change detection approach using remotely sensed data to detect periods of dry down from farmers practicing AWD (especially after the first 20 days of crop growth) may be a preferred option to estimate emissions at scale. The study by Arai et al. (2018) shows an approach that was tested in the Mekong Delta in Vietnam which substitutes certain scaling factors in the Tier1 IPCC guideline methodology with only the transparent satellite-observable explanatory variables. Both Arai et al. (2018) and Lovell (2019) estimate the degree of inundation/non-inundation reflecting the adoption of AWD across rice production in the Mekong River Delta. There are, however, few studies that go so far as to estimate the implications of technology adoption at scale on methane emissions using satellite data (Lovell, 2019, Arai et al., 2018). Therefore, an area for further research would be to estimate the reduction in methane emissions due to the uptake of AWD water management technology by combining the observations from a remote sensing study with the IPCC methodology for estimating GHG emissions in rice cultivation. Satellite observations should be calibrated by using in-field measurements such as closed chamber gas measurements and/or water level indicators/soil moisture meters.

Table 3 Literature review of peer reviewed articles using satellite data to assess water management in rice cultivation and articles combining satellite data and GHG estimation methods to assess emissions from rice cultivation

Data and method	Results	Limitations	Source
Map paddy area and water management practices: • PALSAR-2 (Phased Array type L-band Synthetic Aperture RADAR) land surface water coverage (LSWC) with several inundation indices of MODIS (Moderate Resolution Imaging Spectroradiometer) and AMSR-2 (Advanced Microwave Scanning Radiometer-2) GHG estimation mehtod: • IPCC Tier 1 methodology	• High PALSAR-2-LSWC values were detected even when MODIS and AMSR-2 inundation index values (MODIS-NDWI and AMSR-2-NDFI) were low • Low values of PALSAR-2-LSWC tended to be less frequently detected as the MODIS-NDWI and AMSR-2-NDFI increased. • Satellite data-based transparent methodology to reproduce field-observed CH_4 emissions by substituting certain major scaling factors of the IPCC-Tier 1 methodology and the potential for PALSAR-2 data to be used to monitor the field inundation status with a high spatial resolution, even when the paddy fields are covered by clouds or rice plants.	• All explanatory parameters were remotely-sensed by satellites, other parameters were omitted (e.g., fertilization rate/timing, soil bio-physicochemical parameters, and rice physiological parameters) • Parameters that were coefficients for the acid sulfate soil type had a large uncertainty and tended to underestimate the cumulative CH_4 emission from acid sulfate soil areas • To implement this methodology in the rice paddies of other countries, the model parameter may have to be recomputed empirically to consider the differences in the conventional rice planting practices (e.g., transplanting vs. direct sowing).	Arai, H., Takeuchi, W., Oyoshi, K., Nguyen, L. D., & Inubushi, K. 2018. Estimation of Methane Emissions from Rice Paddies in the Mekong Delta Based on Land Surface Dynamics Characterization with Remote Sensing. *Remote Sensing*, *10*(9), 1438.
Map paddy area and water management practices: Sentinel-1A, PALSAR-2 and Landsat-8 OLI observations GHG estimation method: • Process-based DNDC	• Satellite remote sensing can detect differences in water management. (Adequate ground truth training and validation data are necessary) • Fusion of SAR and optical satellite data is highly accurate for mapping crop area • Time series (weekly measurements)	• Temporal frequency of Sentinel-1A C-band and PALSAR-2 L-band limited the level of hydroperiod monitoring as daily data are not available. • DNDC methodologies offer more precise results than IPCC methods	Torbick, N., Salas, W., Chowdhury, D., Ingraham, P. and Trinh, M., 2017. Mapping rice greenhouse gas emissions in the Red River Delta, Vietnam. *Carbon Management*, *8*(1), pp.99-108.

model with spatiotemporally explicit earth observations and surveys • Compare DNDC to IPCC Tier 1 estimates.	satellite radar at a moderate scale (10–30 m) allows for characterization of inundation, sowing/transplanting, biomass development and harvest date. • Assessment of hydroperiod (duration, frequency, timing of inundation) can be accurately mapped which can improve efficiency and scalability of MRV tools and water management	but are dependent on precise inputs which, in the case of publicly available data for developing countries, may not exist or are limited at best	
Map paddy area: • COSMO Skymed (CSK) and TerraSAR-X • Rule-based algorithm based on temporal dynamics of the rice crop • GHG estimation method: No calculation	• This study was conducted in 13 sites in 6 countries in South and Southeast Asia with diverse water management, crop establishment and maturity. • 1.6 m ha of rice were mapped with classification accuracies from 85% to 95% • Rice mapping algorithm is robust and the parameters can be suitably tuned using local knowledge and field observations and that large-scale rice monitoring is feasible.	• Requires ancillary information on land use/land cover to improve the classification in wetlands, water tanks or other similar areas • CSK and TerraSAR-X are not free, although the same methodology can be applied using Sentinel 1 SAR.	Nelson et al., 2014. Towards an Operational SAR-Based Rice Monitoring System in Asia. *Remote Sensing* 6(11), 10773-10812.
Map paddy area: • PALSAR • Fine-beam single/dual (FBS/D) mode measurements Observe flood frequency: • ScanSAR Wide-Beam 1 (WB1) • MODIS • High temporal frequency	• Validation found the PALSAR-derived rice paddy extent maps and hydroperiod products to possess very high overall accuracies (95% overall accuracy). • Agreement between MODIS and PALSAR flood products was strong with agreement between 85–94% at four comparison dates. • By using complementing products and the strengths of each instrument, image	• Less frequent overpass of SAR may miss dry-down periods (more frequent overpass with MODIS but at coarser resolution and prone to clouds) • Small-scale farms may be difficult to assess (in this study, all rice paddies under 50 hectares were withheld to assess accuracy using only larger fields)	Torbick, N., Salas, W.A., Hagen, S. and Xiao, X., 2010. Monitoring rice agriculture in the Sacramento Valley, USA with multitemporal PALSAR and MODIS imagery. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *4*(2), pp.451-457.

MODIS products further characterized hydroperiod for each individual rice paddy using a relationship between the Enhanced Vegetation Index (EVI) and the Land Surface Water Index (LSWI) GHG estimation method: • No calculation	acquisition strategies and monitoring protocol can be enhanced.		
Map paddy area: • Envisat ASAR APP data at HH and VV polarisation, IS2 (Image Swath 2, corresponding to incidence angle range of 19.2O – 26.7O) at 35-day repeat interval. GHG estimation method: • No calculation	• Differences between traditional practices and modern practices can be detected by changes in the radar backscattering. At the early stage of the season, direct sowing on fields with rough and wet soil surface provided very high backscatter values for both HH and VV data (about -7 to -2 dB). Around 10 – 20 days after sowing, rice plants attained more or less 20 cm high and field flooding decreases dramatically the backscatter to -18 to -12 dB. The backscatter then increases and reaches a saturation level (-2 to 1 and -9 to -7 for HH and VV, respectively) in the middle of crop cycle.	• Envisat ASAR APP* data has a high accuracy to determine planted rice area (1.3% margin of error when compared to official statistics), but with only 35 day repeat intervals, this system cannot accurately determine the water management throughout the season which is needed to estimate GHG emissions	Lam-Dao, N., Le-Toan, T., Apan, A.A., Bouvet, A., Young, F. and Le-Van, T., 2009. Effects of changing rice cultural practices on C-band synthetic aperture radar backscatter using Envisat advanced synthetic aperture radar data in the Mekong River Delta. *Journal of Applied Remote Sensing*, *3*(1), p.033563.
Map paddy area: • MODIS visible, near infrared and shortwave infrared bands • Calculate vegetation	• Water-sensitive shortwave infrared bands from optical sensors (MODIS and VGT) enables progress beyond other algorithms centered on leaf area index and NDVI	• MODIS 8-day composites generated by selecting the clearest atmospheric condition within an 8-day period for each individual pixel may omit some observations and	Xiao, X., Boles, S., Liu, J., Zhuang, D., Frolking, S., Li, C., Salas, W. and Moore III, B. 2005. Mapping paddy rice agriculture in southern China using multi-temporal MODIS

indices including Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI) and Land Surface Water Index (LSWI) that is sensitive to leaf water and soil moisture GHG estimation method: • No calculation	• Paddy rice mapping algorithm focuses on detection of the critical phase of flooding and transplanting in paddy rice field by identifying temporary increases in a water-sensitive spectral index (LSWI)	prone to residual cloud contamination in tropics • Use of daily MODIS data could improve this, but would require much larger datasets and would introduce a greater probability of cloud contamination. • MODIS has coarse spatial resolution • Rainfall or irrigation events in other croplands and seasonally inundated open wetlands can cause misclassification error.	images. *Remote sensing of environment*, *95*(4), pp.480-492.
Map paddy area: • SAR • JERS-1 SAR imaged with a 358 look angle and a ground resolution of 18 m in both range and azimuth with a 44-day revisit cycle • GIS databases GHG estimation method: • DNDC process-based biogeochemical model	• SAR are ideal for mapping rice paddies owing to its nearly all-weather imaging capabilities and sensitivity to flooded vegetation • Combining routine SAR observations, GIS databases and a process-based biogeochemical model for a decision-support system for mapping and monitoring rice paddies • As part of JAXA's Kyoto & Carbon Initiative (K & CI), an acquisition strategy has been developed which includes ScanSAR data acquisitions every 46 days for a period of 14 months for regional mapping and characterization of wetlands, including rice cultivation	• Regional SAR applications have been hampered by a lack of routine, extensive and well-timed acquisitions of SAR imagery. • DNDC model not suited for developing country context	Salas, W., Boles, S., Li, C., Yeluripati, J.B., Xiao, X., Frolking, S. and Green, P., 2007. Mapping and modelling of greenhouse gas emissions from rice paddies with satellite radar observations and the DNDC biogeochemical model. *Aquatic conservation: Marine and freshwater ecosystems*, *17*(3), pp.319-329.
Map paddy area: • European Space Agency	• By using a beta coefficient of the radar data, the WI avoided the pitfalls of cloud	• The research suggests that future change detection efforts should	Lovell, R.J., 2019. Identifying Alternative Wetting and Drying

Sentinel-1a and 1b radar data • combined with in-situ moisture readings, to determine change detection of a time series wetness index (WI) GHG estimation method: • No calculation	cover, surface roughness, and vegetative interference that arise from the sigma coefficient data. • The analysis illustrated an AWD adoption likelihood scale across the delta and it showed potential for the use of remotely sensed data to detect adoption. • Correlation between the WI values and in situ soil moisture meter readings were most accurate in alluvial soils, illustrating a particularly strong relationship between soil type and WI model robustness.	focus on retrieving a multi-season dataset and employing a power density analysis on the time series data to fully understand the periodicity of dry down patterns. • Did not combine adoption results with GHG estimation procedures resulting only in technology adoption estimations without assessing the GHG implications	(AWD) Adoption in the Vietnamese Mekong River Delta: A Change Detection Approach. *ISPRS International Journal of Geo-Information*, *8*(7), p.312.

Notes: * This satellite died in April 2012 so you can assess the past but can no longer use it from 2012 onwards. However, the method can be adapted using other SAR sensors.

Guidelines and methodologies for estimating GHG emissions	Data input requirements	Limitations	Comparison sources
DNDC Process-based bio-geochemical model	Data input requirements: • Daily minimum air temperature • Daily maximum air temperature • Daily precipitation • Nitrogen deposition • Soil texture (clay content) • Soil pH • Soil organic matter content • Individual crop areas and crop rotations (including double cropping)	• Data requirements not suited to developing country contexts • Not economically viable to measure these on a small-field scale • Model and data acquisition not suited for developing country context • Considered more accurate estimations than IPCC model;	Li, C., Zhuang, Y., Cao, M., Crill, P., Dai, Z., Frolking, S., Moore, B., Salas, W., Song, W. and Wang, X., 2001. Comparing a process-based agro-ecosystem model to the IPCC methodology for developing a national inventory of N2O emissions from arable lands in China. *Nutrient Cycling in Agroecosystems*, *60*(1-3), pp.159-175.

	Synthetic N fertilizer use (type & timing) Tillage management Irrigation management Planting and harvest dates Crop residue management	however, the DNDC model and the IPCC methodology gave similar estimates • Lower uncertainty range (±40%)	
IPCC 2009 Guidelines and methodologies for estimating national inventories of GHG emissions.	Data input requirements: • Area of cultivated organic soil • Total cropland area • Irrigation management • Total harvest • Synthetic N fertilizer use Added in IPCC 2019 update: • Pre-season water management • Crop residue management	• Tier 2 baseline factors for individual country level emissions are much more accurate. • Tier 2 baseline emission factors exist for Vietnam • More economically efficient than DNDC process-based model & provides comparable results • Uncertainty range ±60% (may be lower if using country specific Tier 2 data)	IPCC. Climate Change 2007: The Physical Science Basis. In: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (Eds). Cambridge University Press, Cambridge.

8. Conclusions

Any of the above mentioned approaches to MRV may be sufficient as stand-alone procedures depending on the capacity and context, but in any combination they offer more robust results. Research using in-field closed chamber measurements are necessary for calculating IPCC Tier 2 level estimations and can then be used to generate more accurate default baseline emission factors. However, it is not realistic in economic terms to assume that in-field closed chamber measurements will be performed on a large scale or for small scale low-emission projects given the high associated costs. Continuous research using closed chamber measurements will improve the region-specific and context-specific emission variables overtime so that these may not be necessary at the individual project scale, especially when Tier 2 default factors are available. Additionally, surveying every farmer that may be involved in a project to determine their baseline practice is expensive and not a viable option at scale. The baseline farmer practices should be established using the regularly reported government statistical data. A drawback to this methodology is that compliance to new technologies and agriculture improvement packages touted by government extension may be overstated in these statistical reports compared to what is actually happening in farmers' fields. There, a balance should be drawn between the government statistical reporting and survey results based on a randomized representative sample of farmers within the project boundaries. An estimation of accuracy can then be concluded within a reasonable and acceptable degree of confidence. In addition, this can be coupled with satellite images that provide another source of landscape scale data for confirmation through the triangulation of data. GHG estimates will become more accurate as more of each type of these data are collected. The overall costs to monitor, report, and verify data will also become cheaper over time as the data from in-field measurements become more common, easier, and less expensive through the use of sensors and digital apps and as frequency of image acquisitions of freely available satellites improve, and incorporate machine learning. These combined methodologies will be useful to measure change over time but will require the development and maintenance of a central database to store the data and standardized templates that can be adapted to different regions and countries.

Notes: Error correction in the UNFCCC MRV methodology for AMS.III.AU Methane emission reduction by adjusted water management practice in rice cultivation: the current approach describes a second option to calculate emission reductions (UNFCCC V4.0, 2014, p. 14), where the following default values have been mislabeled as "the adjusted daily emission factor" causing considerable confusion and misinformation. These should be correctly labeled as "emission reduction factors" so the second option can be used to determine project emission values based on the emission reduction from the IPCC tier 2 default baseline values:

"(a) For regions/countries where double cropping is practiced:

(i) Use 1.50 (kgCH4/ha/day) for project activities that shift to intermittent flooding (single aeration);

(ii) Use 1.80 (kgCH4/ha/day) for project activities that shift to intermittent flooding (multiple aeration);

(b) For regions/countries where single cropping is practiced:

(i) Use 0.60 (kgCH4/ha/day) for project activities that shift to intermittent flooding (single aeration);

(ii) Use 0.72 (kgCH4/ha/day) for project activities that shift to intermittent flooding (multiple aeration)."

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Appendix

Sample FARMER SURVEY Questionnaire:

GHG ON-FARM SURVEY (Interviews with farmers)

Designed for GHG calculations in SECTOR

1) Basic production measures:

Rice crop:	1st crop	2nd crop	3rd crop
Area (ha)			
Average yield (ton ha^{-1})			
Variety			
Timing of sowing (approx. date)			
Timing of harvest (approx. date)			

2) What is the typical application of fertilizer (chemical and organic) in your field?

Types Crop:	1st crop	2nd crop	3rd crop
	Chemical fertilizer (kg ha^{-1})		
Urea (46-0-0)			
21-0-0			
16-20-0			
16-16-8			
Others (please add name and			

quantity)			
1)			
2)			
3)			
	Organic fertilizer (kg ha^{-1})		
None			
Commercial fertilizer (brand name)			
Animal manure (type of animal)			
Compost			
Other			

3a) What is the main source of irrigation water for your field (mark only one)?

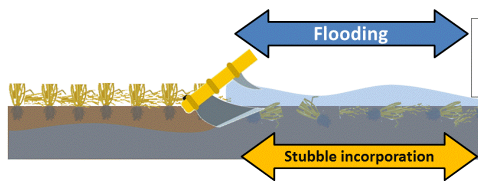
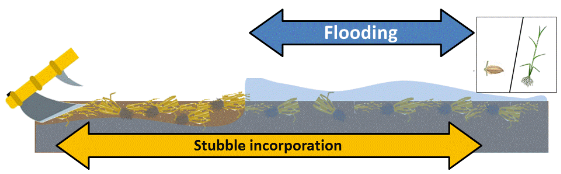
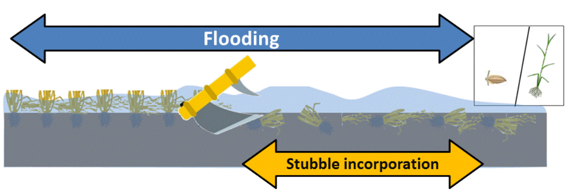
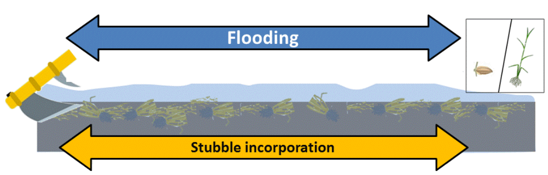
Crop	1st crop	2nd crop	3rd crop
No irrigation (rainfall only)			
Free-flowing irrigation (no pumping)			
Pumped from river/canal			
Pumped from groundwater			

3b) In case of pumping water in and out of the field: How much fuel is required (L)? If unknown, how many times did you pump water in and out of the field each season?

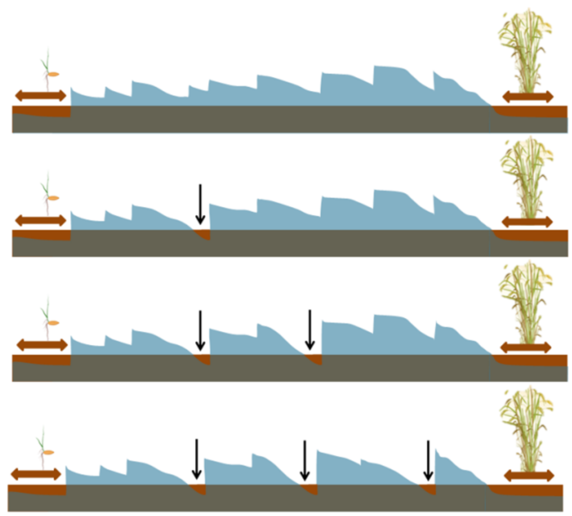
Crop	1st crop	2nd crop	3rd crop
Amount of fuel used for pumping			

(L)			
Number of times pumping			

4) Select the option that best represents your water regime and stubble incorporation into the soil before the next crop is sown

Graphical display	Flooding	Stubble incorp.	1st crop	2nd crop	3rd crop
	Short Less than 4 weeks	Short Less than 4 weeks			
	Short Less than 4 weeks	Long More than 4 weeks			
	Long More than 4 weeks	Short Less than 4 weeks			
	Long More than 4 weeks	Long More than 4 weeks			

5) Select the option that best represents your water regime <u>during</u> each season. How many times is there no water covering your field (i.e., you can see the soil surface) between the times “after sowing” until “draining the field before harvest” in each season?

Graphical display (aeration intervals = arrows)	Name	1st crop	2nd crop	3rd crop.
	Continuous Flooding			
	Single Aeration			
	Multiple aeration (AWD) (please specify number of aerations)			

6a) What are the harvesting methods being used for your field?

Crop	1st crop	2nd crop	3rd crop
Manual cutting and mechanical threshing			
Combine harvester			

6b) How do you manage the rice straw?

Crop	1st crop	2nd crop	3rd crop
Straw burned			
Left on the field and incorporated next season			
Manually collected			

Mechanized collection (using balers or gathering machines)			

6c) In case of straw collection: What is the collected straw used for?

Crop	1st crop	2nd crop	3rd crop
Not known because straw is sold			
Mushroom production			
Composting			
Cow feeding			
Mulching other crops			
Lining material for fruits			
Cattle bedding			

7) How do you manage rice stubble after harvest?

Crop	1st crop	2nd crop	3rd crop
Height of the stubble (cm)			
% of stubble burned			
Burn it right after harvest?			
Burn it right before the next crop?			