Benefits and costs of climate change mitigation technologies in paddy rice

Focus on Bangladesh and Vietnam

Working Paper No. 160

CGIAR Research Program on Climate Change,
Agriculture and Food Security (CCAFS)

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CGIAR

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Abstract

This report examines the costs and benefits of alternate wetting and drying (AWD) in paddy rice production in Bangladesh and Vietnam as a technology that can lead to reduced greenhouse gas (GHG) emissions. AWD is a systematic management practice that involves periodic drying and reflooding of rice fields. Similar water management practices in rice growing have been used in Asian countries for decades, although not optimized for GHG reduction (Richards and Sander 2014).

This report reviews the literature and examines the potential costs and benefits of implementing AWD at national scales in Bangladesh and Vietnam, two countries with current interest in promoting large-scale adoption of AWD. The report summarizes the wealth of information on the agronomic benefits of AWD, yet finds very little evidence of AWD's economic impacts, especially in conjunction with impacts on GHG emissions. The analysis provides a synthesis of the costs and benefits of AWD (e.g., production costs, revenues, yields, other benefits) on a per-hectare basis and a preliminary estimate of the technology's national-level impacts and implementation costs. It must be noted that only one study could be found on the production costs of AWD in Vietnam; thus more representative cost data would be required. Program implementation costs were estimated based on information found in the budgets from a relevant Nationally Appropriate Mitigation Action program in the Philippines and other agriculture sector technical assistance projects

Existing evidence and expert opinion indicate that AWD is very promising in terms of its potential to increase farmers' yields and profits and GHG reduction potential in Bangladesh and Vietnam. Adoption of AWD may allow for additional profit for farmers of between $100 and $400/ha as well as a reduction of 0.8 to 4 tCO_2e/ha. The increased profit is due to decreased irrigation costs and increased yields from the use of AWD.

Keywords

Climate change mitigation; irrigated rice; paddy soil; methane emissions

About the author

Rishi Basak is an independent consultant with 20 years of experience as an analyst and manager in the public and private sectors. He has worked on and contributed to projects in Canada, Chile, China, Colombia, Ghana, India, Mexico, and the United States.

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Contents

Acronyms

AWD	Alternate wetting and drying
CCAFS	CGIAR Research Program on Climate Change, Agriculture and Food Security
CH_4	Methane
CO_2e	Carbon dioxide equivalent
DARD	Department of Agriculture and Rural Development
GHG	Greenhouse gas
Ha	Hectare
IDMCs	Irrigation and Drainage Management Companies
IRRI	International Rice Research Institute
LED	Low emission development
LGED	Local Government Engineering Department
MARD	Ministry of Agriculture and Rural Development
MoA	Ministry of Agriculture
Mt	Mega tonnes (1,000,000 tonnes)
NAMA	Nationally Appropriate Mitigation Actions
N_2O	Nitrous oxide
PIM	Participatory irrigation management
t	Metric tonne
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States dollar

1. Introduction

This report is an output of a project funded by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). The project, “Financing Low Emissions Agriculture,” analyzes the finances needed and gathers empirical evidence to build business cases for supporting transitions to low emissions agriculture in developing countries. The report focuses on alternative technologies and practices that lead to reduced greenhouse gas (GHG) emissions in paddy rice production in Bangladesh and Vietnam—specifically alternate wetting and drying (AWD) technology. Bangladesh and Vietnam were chosen due to the suitability of AWD as a technology and the national interest in scaling up this technology.

The report is organized as follows: Section 2, Approach describes the methodology used to undertake this study. A brief background section then provides an overview of the rice production sector of Bangladesh and Vietnam, including information of the size of the sector and its GHG impact. As water management has a significant impact on GHGs produced in paddy rice farming, a short section is included to describe specific water-related issues and institutions in each of the two countries of focus. The main section of the report focuses on characterizing AWD, including its costs, benefits, and national-level impacts such as emissions reduction potential and corresponding implementation costs and benefits. The final section offers concluding comments and recommendations. Appendix 1 details farm-level impacts, and Appendix 2 describes water use, management, and pricing in more detail. Appendix 3 discusses the expert survey undertaken to gather data and expert opinions to describe this report.

2. Approach

This report is based mainly on a desk review of gray and academic literature. It is not an exhaustive review of the agronomic studies, but rather a review of studies that are relevant to the project’s main objective, which is to gather essential information for business cases for technologies that can reduce GHGs while also benefiting smallholder farmers financially. As such, most studies reviewed focused on the GHG and economic impacts of low emissions technologies in paddy rice. Though principles of meta-synthesis were used for this study, it should not be construed strictly as a meta-synthesis per se.

As suggested by Loevinsohn et al. (2013), a two-stage screening process was used. First, search keys were used in Google Scholar, then paper titles and abstracts of each article were reviewed for their relevance to this study. Studies were excluded if they were not:

- Written in English or French;
- Focused on smallholder farmers;
- In low or lower-middle income countries;
- Focused on rice production.

Retained papers were then screened to exclude those that did not provide data on key elements that we are trying to quantify for this study. At least one of the following key elements needed to be included for it to be retained:

- Costs of production, such as labor and other inputs;
- Benefits of production, including yield and revenues;
- Specific mitigation technologies of interest (e.g., AWD);
- GHG emissions associated with production, including impacts of methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) in overall carbon dioxide equivalents (CO_2e);
- Results specifically for the Bangladeshi or Vietnamese context.

Overall, more than 300 studies were reviewed; ultimately 13 studies were retained.

As this project aims to estimate the costs and benefits for each promising low emissions technology, results from multiple studies were used to fill in information gaps. For instance, one study may have provided data on the GHG reduction potential of a given agricultural practice but not information on the corresponding cost of adoption. Results from another study, or studies, would therefore be required to determine cost of adoption. And yet other study or studies may have been required to determine the cost per metric tonne (t) of emissions reduced, via a process of triangulation.

As scant information on the diffusion rate of AWD was found in the literature, the author developed a credible range for diffusion that was determined based on an expert survey (see Appendix 3). Information gathered from the expert survey, combined with broader information on the diffusion of agricultural technologies found in the literature, contributed to three scenarios developed to estimate national-level impacts of AWD adoption:

1) Business-as-usual scenario: the impacts of AWD in the absence of further efforts to encourage adoption;
2) Conservative scenario: the impacts of AWD if efforts to encourage adoption lead to negligible uptake;
3) Aggressive adoption scenario: the impacts of AWD if donors invest in aggressive diffusion efforts.

Note that all amounts included in this study are in 2014 US dollars (USD), unless stated otherwise.

3. Background

In 2008, Bangladesh had over 4.3 million hectares (ha) in irrigated paddy rice production (FAO AQUASTAT 2011a). In 2005, Bangladeshi rice production was estimated to be responsible for almost 8 mega tonnes (Mt) of CO_2e emissions per year (UNFCCC, n.d.), an average of under 2 tCO_2e/ha. In Vietnam, there are 7.3 million ha in production, with corresponding emissions of 37.4 $MtCO_2$e, an average of 5 tCO_2e/ha. Relative area of production and emissions are shown in figure 1.

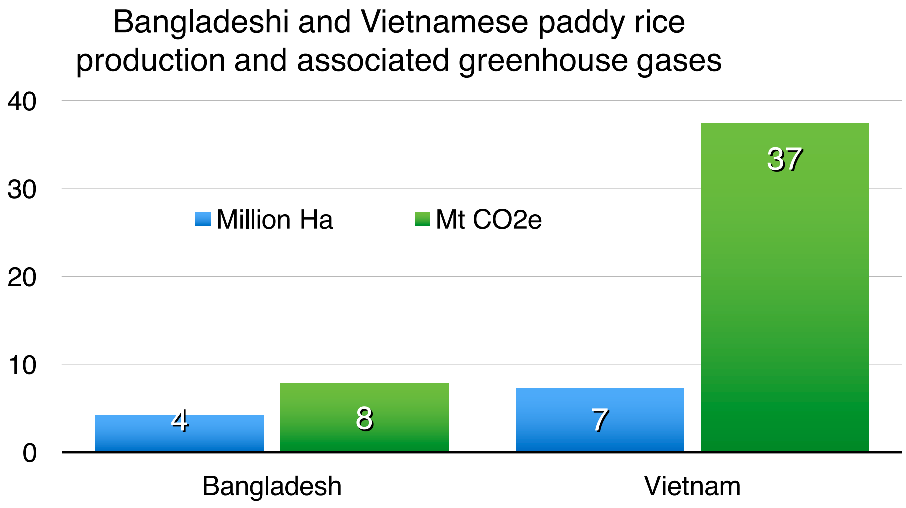
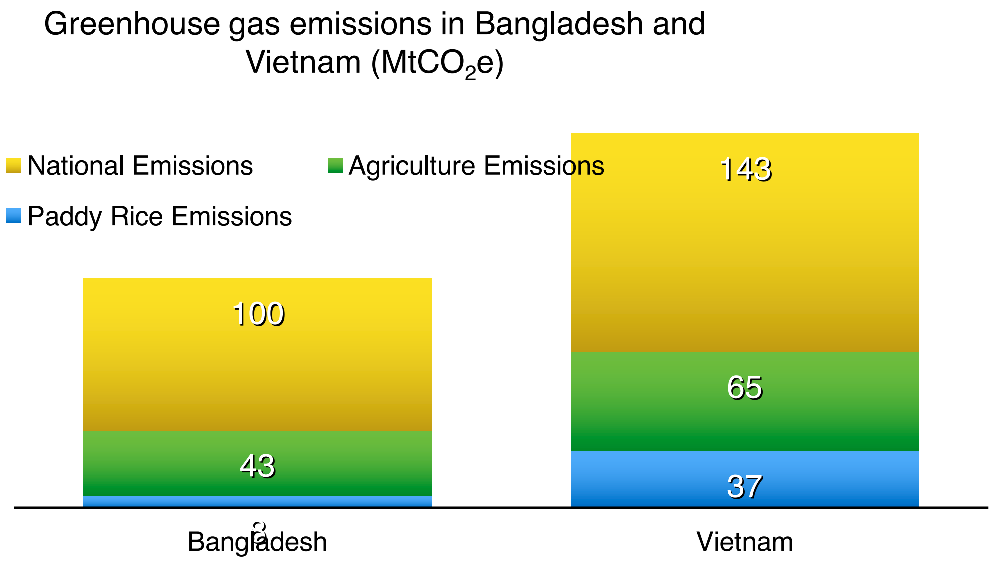


Figure 1. Paddy rice production and associated GHG emissions in Bangladesh and Vietnam.

Figure 2 shows paddy rice emissions from the rice production sector relative to the agriculture and total national emissions in both countries. Paddy rice production in Bangladesh represents 8% of national emissions and 18% of the country's agriculture sector emissions (GoB 2012). Emissions from paddy rice production in Vietnam are much higher and a much larger percentage of the country's agriculture and total emission. Paddy rice production in Vietnam represents 26.1% of national emissions and 58% of the country's agriculture sector emissions (GoV 2014).

Figure 2. Summary of GHG emissions in Bangladesh and Vietnam.



Boro rice (dry season, irrigated rice) accounts for over half of Bangladeshi rice production. It is highly fertilizer and irrigation intensive (Alam et al. 2009), making boro rice a very promising candidate for GHG reductions.

There are three rice-producing regions in Vietnam: the southern delta (including the Mekong Delta), the northern delta, and the northern highlands (where upland rice is grown). The Mekong Delta is the most prominent irrigated rice system in Vietnam (Bong 1999), and produces 50% of total domestic rice. Scientists have found that farmers in the Mekong Delta over-use inputs such as seeds, fertilizer, pesticide, and water by approximately 30% (Ha 2014).

4. Characterization of GHG-reducing technologies: Focus on economics of AWD

Several technologies can reduce GHG emissions from paddy rice production, including:

- AWD
- Straw management
- Short duration seed varieties
- Laser levelling
- Direct-seeded rice

Among the technologies mentioned above, experts in research for development agree that AWD is one of the most promising (Richards and Sander 2014) and so is a focus in the following subsections. AWD is a systematic management practice in paddy rice production that involves periodic drying and reflooding of the field. Similar water management practices in rice production have been used in Asian countries for decades, although not optimized for GHG reduction (ibid.). It has been field-tested in multiple rice-growing regions in the developing world with encouraging results, and has been adopted to a limited extent by farmers in Bangladesh, India, the Philippines, and Vietnam, to name a few. As such, the following subsections focus on AWD.

Information on the implementation costs, benefits, and net impacts is summarized below; results are described on a per-hectare basis for Bangladesh and Vietnam. These results are then used to generate a preliminary estimate of the implementation impacts at the national level for these two countries.

4.1 Farm-level costs

Researchers have estimated the total variable costs of production[1] for conventional paddy rice grown in Bangladesh to be $1,091–$1,184/ha (Alam et al. 2009, Nargis et al. 2009, Basak 2011, Karim et al. 2014). In contrast, the costs of production for AWD paddy rice ranged

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[1] Total variable costs of production include all resources used in producing the crop, including seeds, labor, fertilizer, fuel, and water fees. In some cases, total variable costs also include the cost of capital (i.e., the interest paid on loans). Variable costs do not include the cost to purchase machinery or land.

$1,046–$1,222. Alam et al. (2009)[2] found that AWD led to an increase in variable production costs of 3% ($38/ha) in Bangladesh, whereas a more recent study by Karim et al. (2014)[3] found that AWD led to a decrease in production costs of 4% ($46/ha).

Main cost savings from AWD in Bangladesh arise from lower irrigation costs (water fees and fuel for pumping water) (Alam et al. 2009, Kürschner et al. 2010,[4] Faruki et al. 2011,[5] Karim et al. 2014). Irrigation costs[6] were $23–$42/ha less under AWD (Alam et al. 2009, Kürschner et al. 2010, Karim et al. 2014). Cost increases, on the other hand, arise from higher pre-harvest labor costs and fertilizer. Alam et al. (2009) did not explain why fertilizer cost was higher using AWD or mention whether the results were statistically significant. They did find that weeding was more frequent and labor-intensive in AWD plots than in conventional growing. For instance, in one location (Rangpur), six additional laborers were required to weed 1 ha. Similarly, Kürschner et al. (2010) found that weeding costs were $6–66/ha more under an AWD regime.

The report author found only one study detailing costs of production in Vietnam. Quicho (2013) found that the total costs of production under AWD ($538/ha) were 20% lower than farmers' costs under conventional practice ($676/ha), a decrease of $138/ha.[7] In the same study, an analysis of the cost of specific production inputs found that irrigation costs were 30% lower under AWD production (as was the case for Bangladesh) compared with conventional puddled rice. Specifically, irrigation costs under conventional puddled rice were $41/ha, representing 6% of total variable costs, whereas irrigation costs were $29/ha under AWD—a savings of $12.26, or 2% of total variable costs. **Savings in irrigation costs under AWD were equivalent to a 2.5% increase in profit**. Quicho (ibid.) also found that AWD led

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[2] The on-farm experiments were conducted in Rangpur, Kustia, and Feni, with 29 sample farms from each location (9 AWD farms and 20 conventional farms).

[3] Based on a field experiment in Joydebpur using a two-factor randomized complete block design with three replications.

[4] This study is based on 272 interviews with farmers and pump owners/operators in Rajshahi and Rangpur and nine focus group discussions with farmers and pump owners.

[5] These authors found that AWD cost $38 in fuel versus $47 for conventional puddled rice—a saving of $9/ha.

[6] Irrigation costs under conventional puddled rice in Bangladesh range $183–$300 and represent 17–34% of total variable costs (Karim et al. 2014 and Nargis et al. 2009, respectively).

[7] Based on interviews conducted using a stratified random sample at study sites in six districts in An Giang province.

to a 14–42% decrease in hired labor costs (a reduction of \$11–\$51), although the author provided no explanation.

A study of the Vietnam Low Carbon Rice Project (Ha 2014) found that AWD reduced labor costs by 20–30%, but provided no details on why or on specific labor cost amounts. Owing to this lack of data, more representative cost data are required to fully develop the business case for AWD in Vietnam.

4.2 Farm-level benefits

Yield

In Bangladesh, conventional puddled rice yields 4.6–5.4 t/ha, compared with 5.1–6.2 t/ha under an AWD regime. Yield increases achieved through adoption of AWD in Bangladesh were **5–13% (0.3–0.7 t/ha)** (Alam et al. 2009, Sattar et al. 2009,[8] Kürschner et al. 2010, Karim et al. 2014, Lampayan et al. 2015[9]).

In Vietnam, yields are regularly 5.6–7.9 t/ha under conventional puddled rice and 5.3–7.9 t/ha under AWD (Quicho 2013, Ha 2014, Pandey et al. 2014,[10] Lampayan et al. 2015, Meier unpublished data). Only one of the four studies found in the literature (Pandey et al. 2014) reported results in which AWD could lead to a yield decrease, and the yield difference between the treatments/strategies tested were not statistically significant. As such, the credible range for the potential yield increase from AWD in Vietnam is 0–12% (0.0–0.7 t/ha).

Gross returns

Directly related to the yield impacts of AWD are the corresponding gross returns.[11] The literature shows that gross returns in Bangladesh range from \$1,667 to \$2,386/ha under conventional puddled rice, compared with \$1,750–\$2,523 under AWD (Alam et al. 2009, Karim et al. 2014), representing an **increase in gross returns of 5% (\$83–137/ha)**.

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[8] Based on farm study sites in seven districts with 60 plots, including 3 in AWD at each site; thus, 21 AWD plots in total.

[9] Based on results from 30 farm-level trials in 7 districts across the country, followed by more widespread trials in 460 farmers' fields in 25 districts.

[10] Based on a single field experiment in the Thanh Tri district of Hanoi using a 2 x 4 factorial randomized complete block design.

[11] Gross returns are total revenues received from the sale of the crop before any deductions or allowances (e.g., for rent, cost of goods sold, taxes, etc.). The terms "total revenues" and "gross revenues" are synonymous.

Quicho (2013) found that **AWD led to an increase in gross returns of 6–8% ($100–$120/ha)**,[12] whereas Ha (2014), reporting results from the Vietnam Low Carbon Rice Project, found that the project, which includes an AWD component, led to a 5–10% income increase.

Profit

Farmer profit[13] ranges $575–$1,202/ha for conventional paddy rice grown in Bangladesh and $704–$1,301 for rice grown under AWD (Alam et al. 2009, Kürschner et al. 2010, Karim et al. 2014). This represents an **increase in profit of 8–39%** (**$98–$235/ha**). Alam et al. (2009) and Kürschner et al. (2010) found that the increase in profit stemmed from yield improvement under AWD, whereas Karim et al. (2014) found that profit increased due to both yield improvements and a reduction in irrigation fees paid by farmers.

In Vietnam, farmers' profits under conventional practice are $873–$981/ha and $1,101–$1,341 under AWD (Quicho 2013, Ha 2014). This represents an **increase in profit of 17–41%** (**$170–$391/ha**). This increase in profit was credited to reduced irrigation costs (Quicho 2013) and increased revenues from the sale of extra rice produced (Quicho 2013, Lampayan et al. 2015, Meier unpublished data).

Water

In Bangladesh, researchers found **water savings from AWD to be 22–26%**, representing 2,580–3,590 m^3 of water saved per ha (Sattar et al. 2009, Karim et al. 2014, Lampayan et al. 2015).

In Vietnam, no specific water savings in volume figures could be found, though **water savings associated with AWD adoption were cited as 40–50%** (Ha 2014).

GHG emissions[14]

For Bangladesh, one study with information on GHG emissions associated with conventional puddled rice compared with AWD was found. Ali et al. (2013) reported that conventional

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[12] Revenues under farmers' practice were $1,549–$1,574, whereas revenues under AWD were $1,649–$1,694.

[13] Profit is gross returns minus costs of production, before taxes.

[14] Figures for GHG emissions found in the literature were not based on a full life cycle. For instance, no study included the GHGs associated with fertilizer used in rice growing. Most studies only accounted for the GHGs emitted on site, by the soil and plants, during the rice-growing season (i.e., scope 1 emissions).

puddled rice caused emissions of 3.3 tCO_2e/ha and that implementation of AWD reduced emissions to 2.5 tCO_2e/ha. This is a **reduction of 0.8 tCO_2e/ha, a 24% decrease**. However, the authors did not calculate the GHG emissions associated with diesel fuel used for pumping water. By using fuel savings results from other studies (Alam et al. 2009, Faruki et al. 2011), it can be estimated that AWD may **decrease emissions by 0.032–0.106 tCO_2e/ha via fuel savings alone.**

A study conducted in conjunction with the Vietnam Low Carbon Rice Project (Ha 2014) found that conventional puddled rice was responsible for emissions of 1.1–32.2 tCO_2e/ha, a very wide range. This same study found that the implementation of AWD and other improved agricultural practices resulted in emissions of 0.4–9.4 tCO_2e/ha, an average emissions reduction of 65% (8.8 tCO_2e/ha). Pandey et al. (2014) conducted a field experiment in Thanh Tri district of Hanoi and found that conventional growing was responsible for 2.8 tCO_2e/ha, compared with 1.0 tCO_2e/ha for AWD. Narayan and Belova (2013), who reference simulation results from Applied GeoSolutions (2013), reported emissions of 10.25 tCO_2e/ha for conventional growing, compared with 6.2 tCO_2e/ha for AWD.

Since results from the Ha (2014) study included a "bundle of technologies," as opposed to isolated results for AWD, the present report does not include Ha's figures within the credible range. Using the results from Pandey et al. (2014) and Narayan and Belova (2013), a credible range for the **emissions reduction potential of AWD in Vietnam is 1.8–4.0 tCO_2e/ha (6–39%)**. These results do not include the emissions reduction from fuel savings, as it is not possible to estimate the GHG emissions reduction associated with decreased fuel use without fuel consumption information.

According to Sander (email communication 2015), the difference in the emissions/ha in Bangladesh and Vietnam is due to soil types and the soils' corresponding abilities to store organic carbon.

Table 1 summarizes the farm-level costs and benefits in Bangladesh and Vietnam discussed above. Table 2 shows the benefit/cost ratio for a farmer adopting AWD in Bangladesh and Vietnam, as well as the cost per tCO_2e reduced.

Table 1. Summary of farm-level costs and benefits

Impact/ha	Bangladesh	Vietnam
Variable production costs	⇓ $46/ha to ⇑ $38/ha	⇓ $38/ha
Yield	⇑ 0.3-0.7 t/ha (5-13%)	⇑ 0.0-0.7 t/ha (0-12%)
Gross returns	⇑ $83-$137/ha (5%)	⇑ $100-$120/ha (6-8%)
Profit	⇑ $98-$235/ha (8-39%)	⇑ $170-$391/ha (17-41%)
Water use	⇓ 2,580-3,590 m^3/ha (22-26%)	⇓ 40-50%
GHG emissions	⇓ 0.832-0.906 tCO_2e/ha (24%)	⇓ 1.8-4.0 tCO_2e/ha (6-39%)

Table 2. Benefit/cost ratio and GHG intensity for farmers adopting AWD in Bangladesh and Vietnam

	Bangladesh		Vietnam	
	Low	High	Low	High
Farm-level benefit/cost ratio	1.67	2.06	3.81	3.84
Farm-level cost per tCO_2e/ha	-$118	-$259	-$94	-$98
GHG intensity = tCO_2e/ha/t yield	0.3	0.4	0.2	0.8

The farm-level benefit/cost ratio is significantly higher in Vietnam than in Bangladesh due to the higher profitability of AWD in Vietnam. **The farm-level cost per tCO_2e reduced is negative in both countries because the implementation of the technology is profitable. AWD does not impose additional cost on the farmer.** It must be noted that the benefit/cost ratio and associated calculations for the farmer shown in table 2 differ greatly from the benefit/cost ratio and cost/tCO_2e reduced for program implementation at the national level. This is explained in the subsection "Program implementation costs."

Table 2 also includes values for the GHG intensity of AWD in Bangladesh and Vietnam. In Bangladesh, rice produced using AWD has a GHG intensity of 0.3–0.4 tCO_2e /t yield, compared with 0.6–0.7 tCO_2e/t yield for farmers' conventional practice. In Vietnam, the GHG intensity of AWD is 0.2–0.8 tCO_2e/t yield, compared with 0.5–1.3 tCO_2e/t yield for farmers' practice.

4.3 Estimating national-level impacts

To estimate national-level impacts using the cost and benefit information summarized above, one must consider the financial incentives and barriers to adoption. It is important to note that the costs and benefits (and profitability) of the technology are only one part of the picture: adoption also depends on policy incentives, technical support, farmers' capacity, and other factors. Aspects of national-level impacts are described below and summarized in table 3 at the end of this section.

Financial incentives

The key financial incentive to farmers for AWD adoption is profitability, or AWD's impact on reducing costs and cash outlays. The literature showed that farmers can increase profits by \$98–\$235/ha in Bangladesh and \$170–\$391/ha in Vietnam. Part of this increased profitability is due to water savings. For instance, a 30% reduction in irrigation costs through AWD (as reported by Quicho 2013) is equivalent to an increase in profit of 2.5%. Of course, this applies only when there are real cost savings associated with reduced water use (e.g., reduced water fees, energy costs for pumping). In areas where water is available for free or at a very low cost to farmers, and there are low or no costs to bring the water to the field (e.g., where irrigation canals have been built by the government), the financial incentive to adopt AWD is reduced. Appendix 2 describes water use, management, and pricing in Bangladesh and Vietnam, including descriptions of the institutions involved.

AWD may also increase profits by improving yields by as much as 0.7 t/ha in both Bangladesh and Vietnam. Improved yields, in turn, increase revenues, and therefore profits if the additional amount of rice produced is sold as opposed to consumed by the household.

Barriers to adoption

Lampayan et al. (2015) summarized the barriers to adoption in Bangladesh:

> *The constraints to the uptake of AWD in Bangladesh are mainly institutional in nature. First, the most common arrangements for payment for water – a fixed seasonal rate or a fixed share of the crop – do not provide farmers with an economic incentive to reduce water consumption. Pump owners do not pass on economic benefits from water/energy savings. Negotiating a changed arrangement would require a collective agreement of all farmers in a scheme to implement AWD. The second constraint relates to a lack of organizational willingness for promoting AWD nationally and which organization should be responsible. AWD has been successfully promoted at the local level by NGOs working with the Department of Agricultural Extension, but national or regional campaigns have been lacking. (p. 105)*

In Vietnam, the authors found:

> *The hurdles to adoption were similar to those found in other countries where farmers pay for water from private pump owners. As in Bangladesh, the payments are agreed at the start of the season, usually at a flat rate per area, although it is possible to negotiate a change if all farmers agree. In some locations, pump owners were included in the training, but farmers were still not able to negotiate a reduction in cost. A further obstacle identified by agriculture personnel and farmers was the unevenness of fields, which generally have not been well-levelled. When fields are not level, water may stagnate in depressions, whereas higher parts may become dry. With mostly wet-seeded rice grown in southern Vietnam, an unlevelled field results in uneven crop emergence and uneven early growth, uneven fertilizer distribution and maybe extra weed problems. (p. 106)*

Incentives for AWD are directly linked to the irrigation system. AWD is easily adopted and properly implemented in a pump system where farmers can achieve direct financial savings due to reduced diesel use for pumping. Research has shown that farmers are reluctant to adopt water-saving techniques, and AWD is not carried out properly in irrigation systems where farmers pay seasonal fees independent of actual water usage. For example, this is the case in most areas in the Philippines services by the National Irrigation Administration. With the development and improvement of irrigation canals by NIA as part of the nationwide medium-term plan, the use of pumps would become gradually less important. In turn, this positive development in terms of water access may decrease farmers' incentives to adopt AWD if there are no policies from local governments on water savings to support the practice of AWD. For example, adoption of meter-based (volumetric, consumption-based) water rates instead of fixed area-based rates would promote water-saving practices. Volumetric pricing of irrigation water would induce incentives for better collective action toward saving water resources, as opposed to area-based pricing, in which there is no marginal cost of using water (Tsusaka et al. 2015).

An expert survey, described in detail in Appendix 3, was conducted to identify barriers to AWD adoption for this CCAFS study on financing low emissions agriculture. One question posed to experts was, "In your expert opinion, what is preventing farmers from adopting this technology?" Experts reported the following, by country.

Barriers to AWD adoption in Bangladesh:

- Farmers do not see an incentive, as water is not paid on a volume basis.

- Fields are not levelled well enough.
- Unless a payment for a water-used system is introduced, AWD will not be adopted.
- There is low awareness of this technology's benefits.
- Farmers lack incentives to adopt; it is perceived that only pump owners will benefit.
- There is lack of government support.

Barriers to AWD adoption in Vietnam:

- Farmers do not see an incentive, as water is not paid on a volume basis.
- Fields are not levelled well enough.
- AWD does not show clear economic benefit to farmers.
- Very fragmented fields make it hard to do land consolidation.
- Uneven fields that change elevation from plot to plot make it difficult to control water level and soil moisture.
- There are inadequate irrigation and drainage systems.
- There are complicated irrigation schemes.
- AWD technology and teaching needs to be very well organized (i.e., by commune or villages).
- Abundance of water in the delta translates to a lack of incentive mechanisms.
- There is lack of knowledge about the technology.
- There is a lack of relevant policies to encourage the farmers in application of AWD.
- There is lack of funds for land consolidation and to improve on-farm irrigation facilities.

The expert survey also asked, "In your expert opinion, what would be required in a Nationally Appropriate Mitigation Action (NAMA) to help increase the adoption of this technology?" This question aimed to explore how to remove the above-stated barriers. Experts' suggestions for policy components to increase adoption of AWD in Bangladesh included:

- Provide an incentive for farmers (e.g., reduced fee for water if AWD is applied).
- Encourage pump owners to sell water on a volume or time basis.
- Introduce a metering system.
- Should increase awareness of farmers through demonstration projects.
- Make AWD pipes available in the market.
- Should increase private sector (AWD pipe-making company) engagement and ensure good business model to make the AWD pipes available at the dealer and retailer level.

- Train more farmers.
- Provide incentive mechanisms in the form of an irrigation fee subsidy.
- Link with other service providers and other “extension/dissemination organizations” to reach more farmers.

Experts’ suggestions for policy components to increase adoption of AWD in Vietnam included:

- Provide an incentive for farmers (e.g., reduced fee for water if AWD is applied).
- Recognize AWD as an advanced technology in rice production and mainstream it into the national agriculture development planning.
- Improve land levelling.
- Support land consolidation.
- Improve organizations (by commune or villages).
- Provide a budget to support farmers to have field activities (i.e., applied fertilizer in same time).
- Link with carbon trade or carbon certificates like the Clean Development Mechanism or Reducing Emissions from Deforestation and Forest Degradation Plus.
- Devise incentive mechanisms. Reach out to more farmers to be trained in the technology. Government should provide policies to support the farmers.
- Develop policies around on-farm development, land consolidation, and water saving in irrigated rice.
- Review good practice models on AWD to get the lessons learned for scaling up.
- Organize study tours and workshops on AWD to disseminate the good results and experiences to relevant agencies and farmers.

The International Rice Research Institute (IRRI) is also studying specific barriers to adoption of rice production technologies and expects to release results in 2016. This may enable the preliminary impact scenarios developed below to be fine-tuned and could reveal strategies to remove these barriers and increase adoption of AWD.

Developing scenarios

In the absence of a comprehensive characterization of water-pricing regimes across Bangladesh and Vietnam, this study has used a scenario-based approach to estimate the national-level impacts of AWD adoption:

- For the business-as-usual scenario, a 1% diffusion rate is used (i.e., each year, an additional 1% of the total puddle rice-growing area would be converted to AWD) based on feedback received in the expert survey.
- A conservative scenario of 2% diffusion per year (i.e., each year, 2% more land would be converted from puddled rice to AWD) based on feedback received in the expert survey and in line with Bockel and Touchemoulin (2011)[15] and Lampayan et al. (2015).
- An aggressive diffusion scenario of 10%/year, which would require significant resources to mobilize stakeholders to ensure a high level of adoption in most puddled rice-growing regions in the two countries.[16] Again, this is based on feedback received in the expert survey.

It should be noted that significantly higher diffusion rates have been observed for other types of agricultural technologies in developing countries. For instance, Erenstein (2010) found that zero-tillage drills were found to have diffused at a rate of over 150% in the Indo-Gangetic Plains in the early 2000s. Similarly, Azeem et al. (1989) found that the diffusion rate for new wheat varieties in India during the mid-1980's was 28%. The "off-the-shelf" nature of these technologies increased the ease of uptake and explains their high diffusion rate, compared with estimates for more knowledge-intensive technologies such as AWD.

Total land area under AWD

In Bangladesh, the total land area under AWD could increase by 215,000 ha to a total of 1.9 million ha over five years if an aggressive diffusion scenario, including a strong dissemination program, is put in place. In the case of Vietnam, the total land area under AWD could increase by 340,000 ha to 3 million ha.

National GHG reductions

Materiality is an important consideration in the context of projects financing climate change mitigation, including NAMAs. As such, determining the GHG reduction potential of AWD if mainstreamed across Bangladesh and Vietnam is key to assess whether this technology is, on

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[15] The modelling of Bockel and Touchemoulin (2011) assumed a 10% increase in diffusion of climate-smart agricultural practices over a six-year period (1.6% per annum).

[16] For instance, the NAMA for the rice sector in the Philippines is targeting 100% of farmers in the Philippines cultivating irrigated rice. As such, they are planning to train 150 irrigation officers and are allocating $16 million over five years for training and program management. See http://procurement-notices.undp.org/view_file.cfm?doc_id=34218 for details.

its own or as part of a broader suite of technologies, promising enough to attract domestic or international financing support.

National GHG reductions stemming from the adoption of AWD are estimated at **0.2–1.8 million tCO_2e/year for Bangladesh**. This decrease represents between 0.2% and 1.8% of national emissions in Bangladesh, or 3–23% of the country's agriculture sector emissions. Adoption of AWD could lead to a decrease in GHGs of **0.6–12.2 million tCO_2e/year in Vietnam**. These reductions represent 0.4–8.5% of the country's national emissions and 1.6–33.0% of agriculture sector emissions.

National water savings

The significant water savings associated with AWD at the farm level translate to substantive figures at the national level. In Bangladesh, 738–8,308 million m^3 of water could be saved annually; in Vietnam, 297–9,611 million m^3 of water could be saved. A comprehensive hydrological study is needed to determine how this could potentially improve water availability in the two countries, which could in turn lead to further agricultural and health benefits in certain areas.

National yield impacts

Extrapolating from the credible range of yield impacts from AWD adoption in the studies found, the total rice yield can be expected to increase by 58–1,355 kilotons by 2020 across Bangladesh through the adoption of AWD. In Vietnam, yields could remain unchanged or could increase by as much as 2.1 million t. These are incremental yield estimates (yield increases over and above the business-as-usual scenario).

National profits generated

On the basis of the credible range of profitability impacts from AWD found in the literature and on the potential diffusion rates chosen for our scenarios, the implementation of AWD could lead to increased annual profits of $21 million to $455 million across Bangladesh. Implementation of AWD in Vietnam could generate additional annual profits of $58 million to $1,196 million.

Table 3. Summary of national-level impacts

National-level impacts	**Bangladesh**	**Vietnam**
Current land area where AWD has been adopted	120,000-215,000 ha	50,000-245,000 ha
Additional area with AWD in 5 years under business-as-usual scenario	215,000 ha	340,000 ha
Additional area (over business-as-usual) with AWD in 5 years with NAMA	215,000-1,935,000 ha	340,000-3,060,000 ha
Annual GHG reductions from AWD in 5 years with NAMA	0.2-1.8 million tCO_2e	0.6-12.2 million tCO_2e
Annual H_2O reductions from AWD in 5 years with NAMA	738-8,308 million m^3	297-9,611 million m^3
Annual yield increase from AWD in 5 years with NAMA	58,000-1,355,000 t	0-2142 t
Annual increased profit from AWD in 5 years with NAMA	$21 million-$455 million	$58 million-$1,196 million

4.4 Program implementation costs

To produce the impacts summarized above, resources would be needed for the implementation of a low emissions program or policy (e.g., NAMA, private sector partnership, other financing mechanism) in the areas of technical assistance, capacity building, outreach activities, and building partnerships with key stakeholders (e.g., farmers' groups and advisors). Information on the estimated implementation costs for NAMAs in various stages (e.g., implementation phase,[17] agriculture sector technical assistance projects[18]) follows. This information serves as examples of different implementation strategies:

- The Rural Development in Namibia NAMA has a total budget of $14.4 million over five years, with over $2.9 million allocated over five years for capacity building.
- The Self-Supply Renewable Energy NAMA in Chile allocated $1.5 million toward capacity building out of a total budget of $60 million ($15 million in external financial support). It is estimated that 1.7 million tCO_2e could be reduced per year through implementation of this NAMA.

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[17] Rural Development in Namibia NAMA (http://www.undp.org/content/dam/undp/library/Environment%20and%20Energy/MDG%20Carbon%20Facility/NAMIBIA_final%20NAMA.pdf);
NAMA for Self-Supply Renewable Energy in Chile (http://unfccc.int/files/cooperation_support/nama/application/pdf/nama-seeking-support-for-implementation-re-chile-dic-2012.pdf);
Rural Electrification with Renewable Energy in The Gambia NAMA (http://www.undp.org/content/dam/undp/library/Environment%20and%20Energy/MDG%20Carbon%20Facility/The%20Gambia%20NAMA%20final%202.pdf);
Philippines rice sector NAMA (http://www.undp.org/content/dam/undp/library/Environment%20and%20Energy/MDG%20Carbon%20Facility/AMIA%20Philippines.pdf]);
Costa Rica Coffee Sector NAMA (http://www.nama-database.org/index.php/NAMAs_in_the_Costa_Rican_coffee_sector);
NAMA to Promote the cultivation of Upland High-yielding Rice varieties (Gambia) (http://www.nama-database.org/index.php/Promote_the_cultivation_of_Upland_High-yielding_Rice_varieties).

[18] Private Public Sector Partnership on Capacity Building for Sustainable Land Management in the Shire River Basin (http://www.mw.undp.org/content/malawi/en/home/operations/projects/environment_and_energy/sustainable-land-management-project.html);
Conservation and Adaptive Management of Globally Important Agricultural Heritage Systems (http://www.fao.org/fileadmin/templates/giahs/PDF/GIAHS_FSP_Document.pdf).

- The total amount allocated to capacity development for the Rural Electrification with Renewable Energy in The Gambia NAMA is \$621 million over the first 2 years and \$3 billion over a 15-year period, out of a total budget of \$62.6 billion over 15 years.
- The Private Public Sector Partnership on Capacity Building for Sustainable Land Management in the Shire River Basin (Malawi) NAMA has an annual budget of \$739,000 for five years, with plans to diffuse sustainable land management practices on 800,000 ha, or \$4.62/ha.
- The Conservation and Adaptive Management of Globally Important Agricultural Heritage Systems (Algeria, Chile, China, Peru, the Philippines, and Tunisia) NAMA hopes to introduce conservation and sustainable management on 112,000 ha with a total budget of \$17.9 million, or \$160/ha.
- The NAMA to Promote the Cultivation of Upland High-Yielding Rice Varieties (The Gambia) is seeking \$5.5 million to reduce emissions by 2.8 million tCO_2e/year, which is \$1.96/tCO_2e.
- The Low Carbon Coffee NAMA (Costa Rica), with a budget of \$8.3 million, hopes to reduce GHG emissions by 0.12 million tCO_2e, which is \$69/tCO_2e.
- The Philippines Rice Sector NAMA, with a total budget of \$31.7 million, has a training and technical assistance component of \$16 million over six years to reach 750,000 farmers and diffuse AWD on 750,000 ha. It is estimated that this NAMA would reduce GHG emissions by 12.15 million tCO_2e/year (36.46 tCO_2e over six years), in addition to providing adaptation benefits. The implementation cost is therefore \$21/ha, with a cost of \$0.44/tCO_2e.

Implementation costs of the program depend on its design and scale. For instance, a financing mechanism supporting implementation of AWD in Bangladesh and Vietnam could be solely focused on AWD or could include a suite of technologies, including some focused on adaptation. The technology could be diffused using only technical assistance, or via a mix of government interventions. In terms of scale, the greater the intended diffusion, the greater the costs of outreach, technical assistance, capacity building, and partnership building.

Using the implementation cost of the Philippines rice sector NAMA (\$21/ha) as an illustrative example, Bangladesh would require \$4.5 million–\$40.6 million for implementation based on the conservative or aggressive diffusion scenario. In Vietnam, implementation costs would require \$7.1 million–64.3 million. A summary of estimated costs is shown in table 4.

Table 4. Program implementation cost for Bangladesh and Vietnam

	Bangladesh		**Vietnam**	
	Low	**High**	**Low**	**High**
Program implementation cost (in millions)	\$4.5	\$40.6	\$7.1	\$64.3

This estimated cost summary assumes a low emissions development project package of similar complexity to that of the Philippines rice sector NAMA, which includes an adaptation component. An analysis of the detailed budget for the Philippines rice sector NAMA would need to be undertaken to determine whether all relevant cost items are included (and sufficient for program delivery). Cost would also be based on the strength of institutions and partnerships in Bangladesh and Vietnam in order to determine whether these implementation cost figures would be realistic.

Using the above program implementation cost estimates, it is possible to calculate the benefit/cost ratio[19] for the investment required to implement a countrywide NAMA in Bangladesh and Vietnam, as well as the cost per tCO_2e (see table 5).

Table 5. Program benefit/cost ratio cost per tCO_2e

	Bangladesh		**Vietnam**	
	Low	**High**	**Low**	**High**
Program benefit/cost ratio	21.1	39.6	40.0	65.9
Program cost per tCO_2e	\$2.85	\$3.10	\$0.65	\$1.56

Note that the figures above differ greatly from the farm-level benefit/cost ratio and farm-level cost per tCO_2e reduced.[20] This benefit/cost ratio is calculated by dividing the present value of the national annual increase in profits by the present value of the total low emissions project implementation cost[21] and the opportunity cost of the farmers to participate in training

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[19] The benefit/cost ratio is the ratio between the present value of the benefit stream and the present value of the cost stream. It provides an indication of how much the benefits of the project/program exceed its costs.

[20] Farm-level benefit/cost ratio for Bangladesh is \$1.67–2.06; for Vietnam it is \$3.81–3.84. Farm-level cost per tCO_2e for Bangladesh is -\$118 to -\$259; for Vietnam it is -\$94 to \$-98.

[21] Using a 3% discount rate and a period of 10 years. This assumes that AWD would continue to be implemented for 5 years after full implementation.

sessions.[22] This is a measure of the benefits to all farmers stemming from donor investment in the project.[23] It would also be possible to calculate the benefit/cost ratio to the donor, using a price per tCO_2e as the numerator. In other words, the benefit to the donor would be the value of the tCO_2e reduced, and the cost would be the donor investment in the project (i.e., the project implementation cost).[24]

The cost per tCO_2e is calculated by dividing the present value of the total project implementation cost by the total GHGs reduced over a 10-year period.[25] As such, the project cost per tCO_2e can be construed as the cost per tCO_2e financed by the donor(s).

5. Conclusion and recommendations

Results from the literature and the expert survey indicate that AWD is promising in terms of its potential to both reduce GHGs and increase farmers' yields and profits. Using a set of simplifying assumptions, the cost per tCO_2e reduced and the benefit/cost ratio were calculated and shown to be attractive. These encouraging results hold for both Bangladesh and Vietnam.

The adoption rate for AWD will depend on myriad factors, including level of outreach efforts, strength of partnerships with key stakeholders (e.g., farmers' groups and advisors), ability to remove barriers to adoption, and extent to which farmers have a clear financial incentive to adopt. As such, focusing mainstreaming efforts in regions where farmers face higher irrigation costs (e.g., where they pay water fees, where energy costs for water pumping are significant) will likely lead to greater adoption rates. To increase the likelihood of success, it may be beneficial to engage with government officials and/or other key players (e.g.,

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[22] Based on a one- to two-day time investment (one training day plus one field day), using a wage rate of \$3.29–\$5.00/day for Bangladesh (Nargis et al. 2009, Wiggins and Keats 2014) and \$1.21–\$5.00/day for Vietnam (Minh 2013, Wiggins and Keats 2014).

[23] The research and development costs of the technology are not included in this calculation because this is a sunk cost (i.e., the cost has already been incurred and cannot be recovered), and the technology is a public good. Lampayan et al. (2015) reported that this cost is \$2.09 million (based on IRRI's financial data collected by the Water-Savings Workgroup of the IRRC).

[24] For instance, if a price per tCO_2e of \$5 is used, the benefit/cost ratio to the donor would be 1.6–1.8 for Bangladesh and 3.2–7.8 for Vietnam. This assumes a ramping up of GHG reductions starting in year 2 of the program and uses the present value of NAMA implementation costs.

irrigation service companies) to institute water payment schemes that would create an incentive to save water.

Another key consideration is the yield gap. Identifying areas where puddle rice productivity is low could be another way to target efforts, as yield increases stemming from AWD may be a sufficient financial incentive to adopt the technology in those areas (i.e., even in areas where irrigation water is free).

Several information gaps have been identified. There is a need to gather more information on:

- Circumstances under which AWD could lead to increases in weeds and the associated weeding costs;
- Circumstances where AWD does not increase yields or could potentially lead to decreases in yields;
- Emissions impacts of AWD under various soil types and climatic conditions;
- Amount of fuel used for water pumping and irrigation, so that overall scope of GHG emissions can be better estimated.

5.1 Going beyond agronomic impacts

It is recommended that future field studies include an analysis of the economic impacts of technologies in addition to the overall GHG impact (i.e., CH_4 and N_2O—overall scope 1 emission reduction potential due to crop, soil, and fuel use in CO_2e) and agronomic benefits. Special attention should be placed on:

- Costs of production (under conventional and AWD regimes) in Vietnam, as only one study could be found;
- Specific areas and number of farmers that face water fees and pumping costs, including what fraction of total variable costs this represents;
- Labor costs.

Economic impacts should be analyzed over the short, medium, and long terms to determine how costs and benefits vary over time. This would enable a better assessment of the financing requirements for a specific low emissions development program (e.g., short-term credit could be an appropriate solution if most costs associated with adoption are up-front costs and if financial benefits can be reaped early on by farmers). Analysis over time may also better capture unintended consequences of technologies. For instance, for technologies that entail increased field traffic (e.g., split fertilizer application), field studies may include an assessment of soil compaction and its long-term impact on productivity.

Future field studies should include measurements of positive and negative externalities associated with the technologies, such as adaptation benefits, water pollution impacts, and the provision of other ecosystem services (e.g., impact on water availability and quality, especially in areas where shortages are frequent and where water pollution is a problem). Having a more comprehensive suite of economic, social, and environmental information is crucial to building solid business cases for low emissions technologies that have demonstrated significant agronomic benefits.

Research is needed on the analytics required for implementation, for example, in determining:

- How to more cost-effectively implement the technologies;
- The regions and specific agronomic, economic, and institutional conditions under which technologies are most financially attractive;
- Specific barriers to implementation and likely mitigation measures to alleviate or eliminate these barriers.

5.2 Going beyond farm-level analysis

This report focused on farm-level benefits and costs of paddy rice management technologies. To develop a low emission development (LED) program proposal, the following broader national impacts and implementation issues need to be more completely analyzed:

- What specific resources are required to upscale the technologies (e.g., information dissemination, capacity building, partnership building)? What are their corresponding costs?
- How can implementation be done most effectively (e.g., by bundling technologies and policy instruments, by aligning with existing and proposed government priorities)?
- What is the role of and impacts on government? This should include policy instruments the government can put in place to support LED objectives (e.g., irrigation fees, regulations, integration within a broader technical assistance program) and fiscal impacts of the implementation of the LED program (e.g., loss of revenue from irrigation fees, reduced need to invest in irrigation infrastructure).

To generate a more robust information base, a solid sector profile is needed. The profile should include the number of farmers and their specific locations, number of hectares under production, water fees, current agricultural practices, yields, estimated GHGs, and water usage and fuel consumption associated with current production. This would populate the baseline and business-as-usual scenario, and would improve the robustness of the monitoring, reporting, and verification system that would be needed for an eventual LED program.

Appendix 1. Detailed farm-level impact tables

	Farmers' practice (conventional puddled rice)		**AWD**		**Change**	
BANGLADESH	**Low**	**High**	**Low**	**High**	**Low**	**High**
COSTS						
LABOR						
Land prep	$140.50	$194.21	$140.44	$207.88	-0%	7%
Pre-harvest labor	$124.60	$294.49	$126.02	$315.50	1%	7%
Harvesting, carrying, & threshing	$199.23	$232.92	$234.32	$269.56	18%	16%
INPUTS						
Seed & seedbed	$45.61	$69.01	$74.84	$74.84	64%	8%
Fertilizer	$110.93	$176.31	$189.62	$189.62	71%	8%
Herbicide	$4.89	$9.26	$5.94	$5.94	21%	-36%
Insecticide	$17.59	$17.59	$18.87	$18.87	7%	7%
Irrigation fees	$183.21	$299.64	$140.77	$140.77	-23%	-53%
Fuel for irrigation	$47.00	$47.00	$37.84	$37.84	-19%	-19%
Electricity for irrigation (kWh)	4,593	4,593	3,543	3,543	-23%	-23%
TOTAL VARIABLE COSTS OF PRODUCTION	$1,091.64	$1,184.01	$1,045.80	$1,222.40	-4%	3%
BENEFITS						
Yield (t/ha)	4.6	5.45	5.6	6.2	22%	14%
Gross return	$1,667.11	$2,386.41	$1,749.52	$2,523.27	5%	6%
Emissions (from practice) (t/ha)	3.26		2.48	60% reduction	-24%	-60%
Emissions (from fuel)	0.163		0.132		-30%	
Water (m^3)	5,900	17,367	4,520	12,400	-23%	-29%
PROFIT/HA	$575.47	$1,202.40	$703.72	$1,300.86	22%	39%
BENEFIT/COST RATIO	1.53	2.02	1.67	2.06	10%	2%
INPUT COST/T RICE	$88.96	$104.92	$83.55	$69.50	-6%	-34%
LABOR COST/T RICE	$100.94	$132.41	$89.43	$127.89	-11%	-3%
VARIABLE COST/T RICE	$237.31	$217.25	$186.75	$197.16	-21%	-9%

	Farmers' practice (conventional puddled rice)		**AWD**		**Change**	
VIETNAM	**Low**	**High**	**Low**	**High**	**Low**	**High**
COSTS						
INPUTS						
Seed & seedbed	$39.18	$43.81	$45.75	$48.00	17%	10%
Fertilizer	$195.68	$238.74	$189.55	$194.68	-3%	-18%
Herbicide	$9.32	$12.66	$9.82	$9.92	5%	-22%
Insecticide	$76.51	$97.14	$57.32	$60.96	-25%	-37%
Irrigation fees	$40.87	$40.87	$28.61	$28.61	-30%	-30%
Fuel for irrigation	$102.97	$102.97	$98.83	$98.83	-4%	-4%
(Partial) VARIABLE COSTS OF PRODUCTION	$464.53	$536.19	$429.88	$441.00	-7%	-18%
BENEFITS						
Yield (t/ha)	5.57	7.79	5.25	7.9	-6%	1%
Gross return	$1,549.26	$1,574.28	$1,639.52	$1,694.14	6%	8%
Emissions (from practice)	2.78	10.25	1.005	6.225	-64%	-39%
Water (m^3)					-40%	-50%
PROFIT/HA	$873.00	$981.00	$1,101.59	$1,341.43	17%	41%
BENEFIT/COST RATIO	3.34	2.94	3.81	3.84	14%	31%
INPUT COST/T RICE	$83.40	$68.83	$81.88	$55.82	-2%	-19%

Appendix 2. Water use, management, and pricing

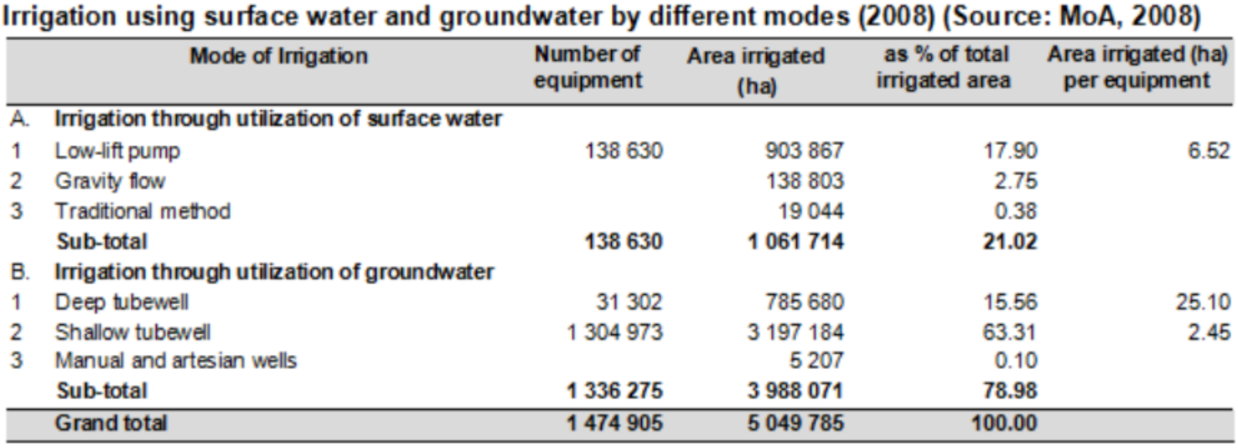
Water is a critical input in rice production. In addition to reducing greenhouse gas (GHG) emissions, the alternate wetting and drying (AWD) rice management practice can reduce water use by up to 30% (Sander et al. 2016). Reduced water use offers economic benefits to farmers, depending on the associated avoided costs (e.g., water fees, energy costs for pumping). As such, Appendix 2 describes specific water use, management, and pricing to provide information for the business case for AWD as a GHG mitigation strategy. The annex also describes the institutions involved in water management, which may prove helpful in identifying key entry points, partnerships, incentives, and potential future policy solutions in mainstreaming AWD.

Bangladesh

In Bangladesh, total water withdrawal for irrigation is an estimated 31.5 km^3, which represents 88% of all withdrawals. In 2008, approximately 28.5 km^3 (79%) of withdrawals were from groundwater. Surface water is used extensively to irrigate boro rice during the dry season (FAO AQUASTAT 2011a, 2012). In 2008, there were 1,304,973 shallow tube wells, 138,630 low-lift pumps, and 29,170 deep tube wells that together irrigated 5 million ha.

Table A2.1 shows the use of different modes of irrigation, and table A2.2 describes the characteristics of shallow and deep tube well systems used for rice irrigation in Bangladesh. Shallow tube wells are located on the largest proportion of irrigated land (63% of total irrigated area), followed by low-lift pumps (18%) and deep tube wells (16%).

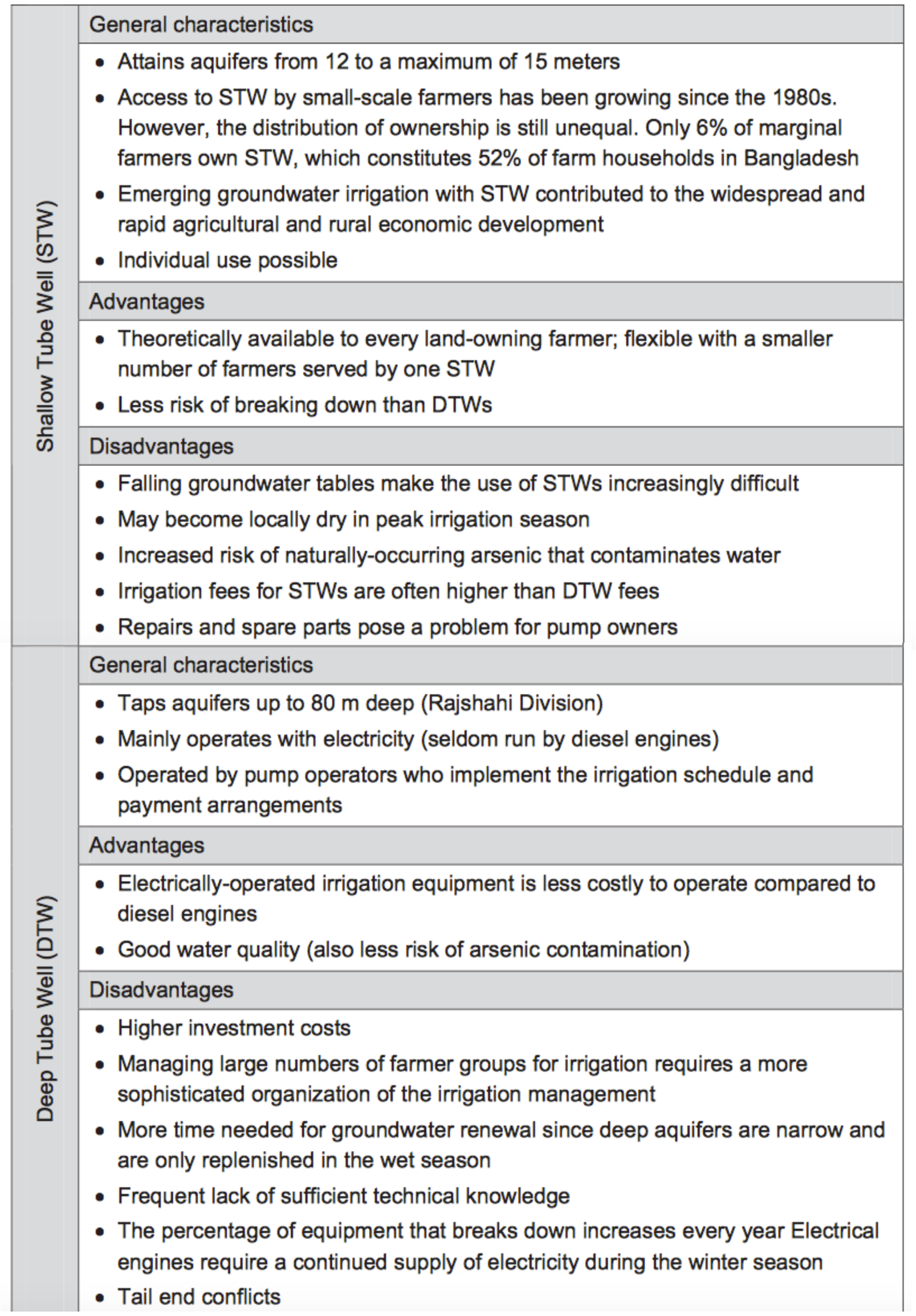
Table A2.1. Modes of irrigation in Bangladesh (MoA 2008)



Irrigation using surface water and groundwater by different modes (2008) (Source: MoA, 2008)

	Mode of Irrigation	Number of equipment	Area irrigated (ha)	as % of total irrigated area	Area irrigated (ha) per equipment
A.	**Irrigation through utilization of surface water**				
1	Low-lift pump	138 630	903 867	17.90	6.52
2	Gravity flow		138 803	2.75	
3	Traditional method		19 044	0.38	
	Sub-total	**138 630**	**1 061 714**	**21.02**	
B.	**Irrigation through utilization of groundwater**				
1	Deep tubewell	31 302	785 680	15.56	25.10
2	Shallow tubewell	1 304 973	3 197 184	63.31	2.45
3	Manual and artesian wells		5 207	0.10	
	Sub-total	**1 336 275**	**3 988 071**	**78.98**	
	Grand total	**1 474 905**	**5 049 785**	**100.00**	

Table A2.2. Characteristics of shallow and deep tube well systems for rice irrigation



Shallow Tube Well (STW)	General characteristics	• Attains aquifers from 12 to a maximum of 15 meters • Access to STW by small-scale farmers has been growing since the 1980s. However, the distribution of ownership is still unequal. Only 6% of marginal farmers own STW, which constitutes 52% of farm households in Bangladesh • Emerging groundwater irrigation with STW contributed to the widespread and rapid agricultural and rural economic development • Individual use possible
	Advantages	• Theoretically available to every land-owning farmer; flexible with a smaller number of farmers served by one STW • Less risk of breaking down than DTWs
	Disadvantages	• Falling groundwater tables make the use of STWs increasingly difficult • May become locally dry in peak irrigation season • Increased risk of naturally-occurring arsenic that contaminates water • Irrigation fees for STWs are often higher than DTW fees • Repairs and spare parts pose a problem for pump owners
Deep Tube Well (DTW)	General characteristics	• Taps aquifers up to 80 m deep (Rajshahi Division) • Mainly operates with electricity (seldom run by diesel engines) • Operated by pump operators who implement the irrigation schedule and payment arrangements
	Advantages	• Electrically-operated irrigation equipment is less costly to operate compared to diesel engines • Good water quality (also less risk of arsenic contamination)
	Disadvantages	• Higher investment costs • Managing large numbers of farmer groups for irrigation requires a more sophisticated organization of the irrigation management • More time needed for groundwater renewal since deep aquifers are narrow and are only replenished in the wet season • Frequent lack of sufficient technical knowledge • The percentage of equipment that breaks down increases every year Electrical engines require a continued supply of electricity during the winter season • Tail end conflicts

Source: Kürschner et al. 2010.

Irrigated rice is found on 4.3 million ha, approximately 85% of irrigated land in Bangladesh.

Figure A2.1 shows the amount of land under irrigation by crop.

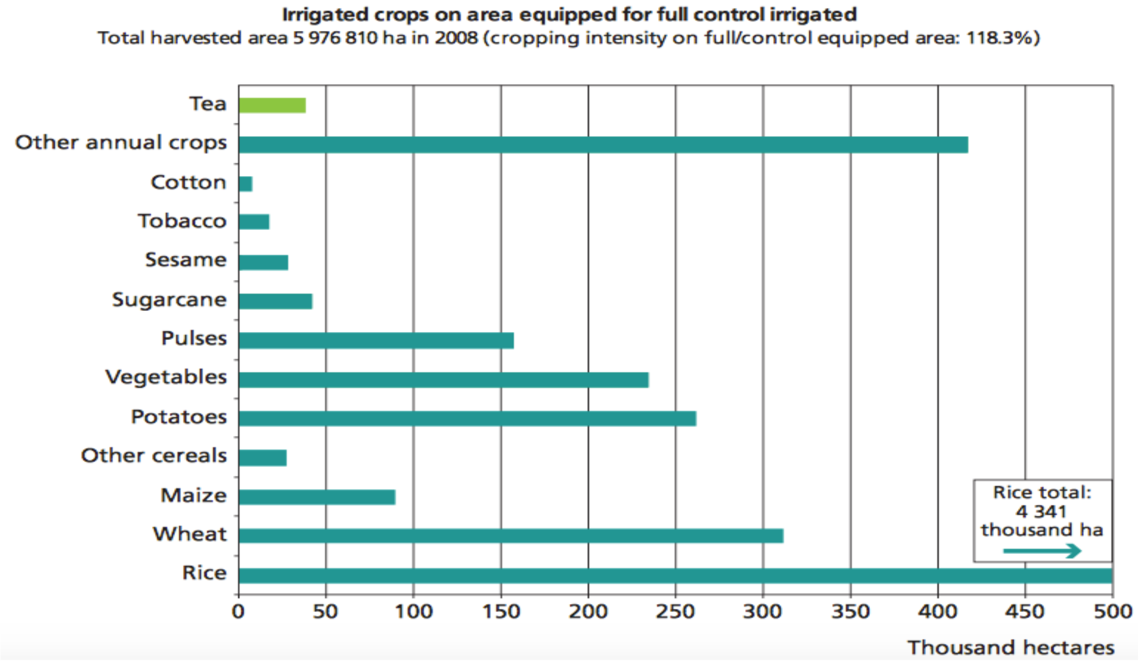


Figure A2.1. Irrigated crops in areas with full irrigation capabilities in Bangladesh (Frenken 2012).

Institutions

Three ministries share the responsibilities in irrigation water management in Bangladesh. "Minor irrigation" is under the jurisdiction of the Ministry of Agriculture (MoA). Small-scale surface irrigation is the responsibility of the Ministry of Local Government, Rural Development and Cooperatives (MoLG&RD). Large-scale irrigation is under the Ministry of Water Resources (MoWR). Frenken explained the roles of each institution in his 2012 article:

> **The MoA**
>
> The MoA is mainly concerned with agricultural policy development, planning and monitoring. Project delivery is the responsibility of its various agencies, the most important being the Bangladesh Agricultural Development Corporation (BADC). In the past, the BADC was directly involved in supplying inputs to minor irrigation and looked after the O&M of all sorts of equipment. It has now withdrawn from all commercial operations relating to minor irrigation, leaving them to the private sector. The Department of Agriculture Extension demonstrates and extends information to farmers on crops, agronomic practices and use of on-farm water management and agricultural machinery. The Barind Multipurpose Development Authority, under the MoA is also responsible for water resources management in agricultural development of the Barind Tracts region.

The MoLG&RD

The Local Government Engineering Department (LGED), under the Ministry of Local Government, Rural Development and Cooperatives (MoLG&RD), implemented Small-Scale Water Resources Development (SSWRD) projects Phase I and II by constructing 26 rubber dams in the medium and small rivers in different parts of the country. LGED was also responsible for participatory management of these projects, which was achieved by forming the Water Management Cooperative Associations (WMCAs) for each project. The Bangladesh Rural Development Academy (RDA), under the MoLG&RD, is currently implementing a package model of Multipurpose Low-Cost DTW Projects in different parts of the country with a view to achieving optimum utilization of water resources for irrigation, domestic and other purposes such as fisheries, livestock rearing and nurseries. These multiple uses bring significant benefits and contributions to livelihoods, especially for poor households.

The MoWR

Under the MoWR, the Bangladesh Water Development Board is responsible for the planning, implementation and operation of medium- and large-scale surface water irrigation schemes, flood control and flood control and drainage projects. The Water Resources Planning Organization, under the same ministry, has a mandate to ensure coordination of all relevant ministries through the National Water Council and to plan all aspects of water resources development including large-scale and minor irrigation, navigation, fisheries and domestic water supplies.

Irrigation costs

According to a study by Krupnik et al. (2013) from the International Maize and Wheat Improvement Center (CIMMYT), groundwater pumping is associated with high fuel costs, and tube well irrigation is problematic in some regions due to shallow, saline aquifers, high levels of arsenic in the groundwater, and the high cost of deep well installation to reach groundwater. Another irrigation cost is the tariff or fee charged for the water supply service. Many farmers in Bangladesh pay a flat rate to pump owners for the irrigation service. The flat rate is based on the size of the field and not the volume of water used or the number of irrigation events (Price et al. 2013).

The 2009 Bangladesh Water Utilities Data Book reported that households in rural areas under piped, multipurpose irrigation schemes supported by the Rural Development Academy paid a flat fee equivalent to $72/season/ha for irrigation in 2006 (Water and Sanitation Program 2009). Sattar et al. (2009) reported that farmers were paying the equivalent of 25–30% of their rice harvest for irrigation, and these costs were increasing.

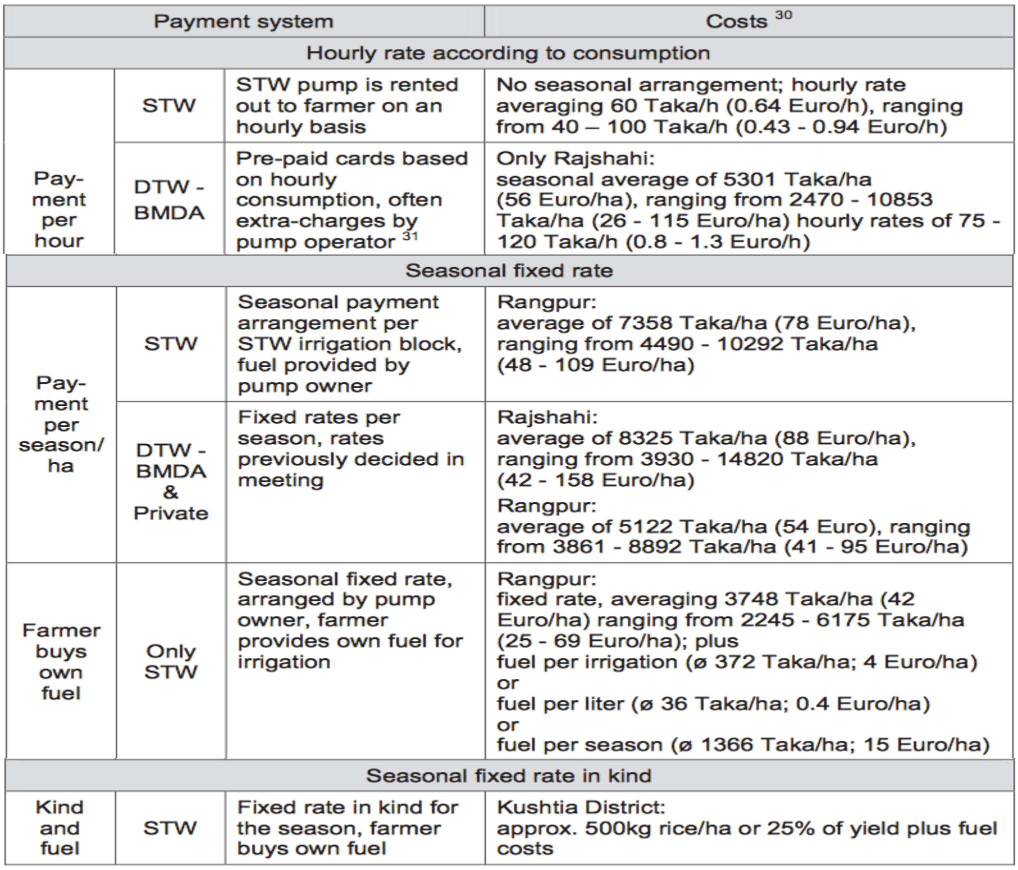
According to Kürschner et al. (2010, p. 55)”

> (T)he payment system plays a crucial role as it determines whether the economic benefits of AWD are transferred to the farmer or remain with the pump owner…fixed (seasonal) and consumption-based rates - have decisive implications on sustainable adoption. The majority of the payment arrangements are based on a seasonal fixed rate. Even…the more sophisticated, consumption-based payment system in DTW systems has been identified to actually function like a seasonal fixed rate system. Indeed, the only true consumption-based payment systems found are ‘fixed rates plus fuel’ (in these cases diesel has to be provided by the farmer according to demand) as well as ‘payment per hour’ by renting out pumps for the time that farmers need to irrigate. Payments in kind were uncommon and found only a few times in Kushtia District.

Payment systems and irrigation costs

Table A2.3 outlines how payments are made for irrigated water in Bangladesh.

Table A2.3. Irrigation payment systems and costs in Bangladesh (Kürschner et al. 2010)*



Payment system			Costs [30]
Hourly rate according to consumption			
Pay-ment per hour	STW	STW pump is rented out to farmer on an hourly basis	No seasonal arrangement; hourly rate averaging 60 Taka/h (0.64 Euro/h), ranging from 40 – 100 Taka/h (0.43 - 0.94 Euro/h)
	DTW - BMDA	Pre-paid cards based on hourly consumption, often extra-charges by pump operator [31]	Only Rajshahi: seasonal average of 5301 Taka/ha (56 Euro/ha), ranging from 2470 - 10853 Taka/ha (26 - 115 Euro/ha) hourly rates of 75 - 120 Taka/h (0.8 - 1.3 Euro/h)
Seasonal fixed rate			
Pay-ment per season/ ha	STW	Seasonal payment arrangement per STW irrigation block, fuel provided by pump owner	Rangpur: average of 7358 Taka/ha (78 Euro/ha), ranging from 4490 - 10292 Taka/ha (48 - 109 Euro/ha)
	DTW - BMDA & Private	Fixed rates per season, rates previously decided in meeting	Rajshahi: average of 8325 Taka/ha (88 Euro/ha), ranging from 3930 - 14820 Taka/ha (42 - 158 Euro/ha) Rangpur: average of 5122 Taka/ha (54 Euro), ranging from 3861 - 8892 Taka/ha (41 - 95 Euro/ha)
Farmer buys own fuel	Only STW	Seasonal fixed rate, arranged by pump owner, farmer provides own fuel for irrigation	Rangpur: fixed rate, averaging 3748 Taka/ha (42 Euro/ha) ranging from 2245 - 6175 Taka/ha (25 - 69 Euro/ha); plus fuel per irrigation (ø 372 Taka/ha; 4 Euro/ha) or fuel per liter (ø 36 Taka/ha; 0.4 Euro/ha) or fuel per season (ø 1366 Taka/ha; 15 Euro/ha)
Seasonal fixed rate in kind			
Kind and fuel	STW	Fixed rate in kind for the season, farmer buys own fuel	Kushtia District: approx. 500kg rice/ha or 25% of yield plus fuel costs

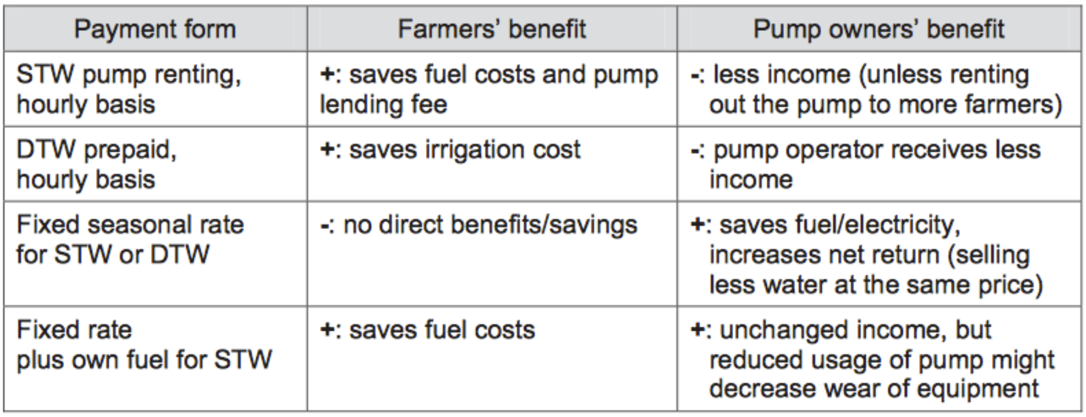
Source: Kürschner et al. 2010.

*Values are in 2009 Bangladeshi Takas and Euros. 2009 conversions: $1 = 67.62 BDT = 0.75 Euros.

Economic benefits of AWD according to the payment form

Different payment forms differentially benefit farmers and pump owners, as described in table A2.4.

Table A2.4. Benefits of different irrigation payment forms*



Payment form	Farmers' benefit	Pump owners' benefit
STW pump renting, hourly basis	+: saves fuel costs and pump lending fee	-: less income (unless renting out the pump to more farmers)
DTW prepaid, hourly basis	+: saves irrigation cost	-: pump operator receives less income
Fixed seasonal rate for STW or DTW	-: no direct benefits/savings	+: saves fuel/electricity, increases net return (selling less water at the same price)
Fixed rate plus own fuel for STW	+: saves fuel costs	+: unchanged income, but reduced usage of pump might decrease wear of equipment

Source: Kürschner et al. 2010.

* +: beneficial; -: no benefits

Kürschner et al. (2010, p. 55) also stated that "(u)sing AWD in the consumption-based shallow tube well-system leads to direct benefits for the farmer, but can lower the profit of the pump owner who is renting the pump to AWD users on a less frequent basis. The pump owner can only make up for this loss by renting the pump to more farmers." The authors analyzed an innovative prepaid card system used in Bangladesh and found that, although this system may theoretically lead to greater farmer benefits, in practice the prepaid cards were only "introduced in a very limited number of deep tube well systems so far." They suggested that "AWD farmers will only benefit if this system is successfully implemented on a large scale, as originally contemplated."

The most common payment scheme in Bangladesh is the fixed-rate payment, which guarantees a regular income to pump owners and provides them with extra benefits from decreased water and energy consumption. Unfortunately, this system requires AWD farmers to pay the same irrigation charge as non-adopters, even though they use less water (ibid.). Kürschner et al. (2012) found that in "none of the reported cases did pump owners reduce the charges for AWD users upon their own initiative (and) …AWD farmers often voiced their skepticism about receiving a reduced rate when being asked what would happen if they actually approached the pump owner on this issue" (p. 56). The authors posited that "only the fixed-rate payment form, in which the farmer provides his own fuel along with a seasonal fixed rate for using the pump, is capable of entailing economic benefits and a fair water allocation to all involved parties." (p. 56).

Lampayan et al. (2015) wrote that a possible solution to this dilemma is via a collectively agreed-upon payment scheme. The authors described a project funded by the United States Agency for International Development in Bangladesh (i.e., the Cereal Systems Initiative for South Asia) that successfully negotiated such a scheme:

> Extension staff sat with the community and the tube-well owners to find a solution to the problem. It was agreed that the farmers would pay for the water at a fixed rate on an hourly basis and that they would use AWD to limit the amount of water used. This would free up spare pumping capacity, allowing the pump owners to sell water to more farmers. This is in fact what happened. The farmers saved money and the pump owners did not lose money. In fact, the pump owners thought it such a good idea that they offered to give the farmers

> pani-pipes to measure water levels and tube-well owners in two neighbouring villages copied the system. (p. 105)

Vietnam

Barker et al. (2004, p. vi), in a comprehensive report on irrigated agriculture in Vietnam, described the wide variety of water-resource and cropping situations:

> The Mekong and Red River deltas are largely devoted to rice production based on surface irrigation. There are seasonal floods and droughts. Thus, expenditures for irrigation include drainage and flood control. Large pumping systems in the North and small private pumps in the South are important for water control. Rapid adoption of small private pumps for both irrigation and drainage, particularly in the Mekong delta, has greatly facilitated crop diversification.

Water withdrawal for irrigation represented 90% of all withdrawals in the country. Surface water withdrawal was around 80 km^3 (98% of total withdrawals) (FAO AQUASTAT 2011b). Figure A2.2 breaks down the water withdrawals by its main sources.

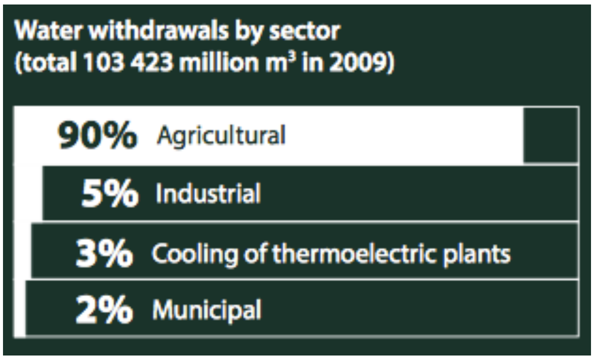


Figure A2.2. Water withdrawals in Vietnam by sector (FAO AQUASTAT 2013).

Surface irrigation accounts for almost all (99.98%) of the total area equipped for irrigation; the remainder is sprinkler irrigation. The total area equipped for irrigation was 4.6 million ha, which represents 45% of the cultivated area in Vietnam in 2011 (FAO AQUASTAT 2013).

There are 1.6 million ha covered by small irrigation systems (< 5,000 ha), 1.2 million ha under medium irrigation schemes (5,000–50,000 ha), and 1.7 million ha under large irrigation schemes (> 50,000 ha). In total, about 2.1 million ha were power irrigated (FAO AQUASTAT 2011b).

Approximately 70% of irrigation is in the Cuu Long and Red-Thai Binh basins. Paddy rice accounts for 82% of the irrigated area (Kellogg 2009). Almost three-quarters of Vietnamese rice production comes from irrigated fields; rain-fed rice accounts for 18% of the domestic production (Sandin 2005). In 2005, rice was grown on 6.6 million ha of irrigated land, representing 78% of the total domestic harvested area. Figure A2.3 shows irrigated crops in Vietnam by ha.

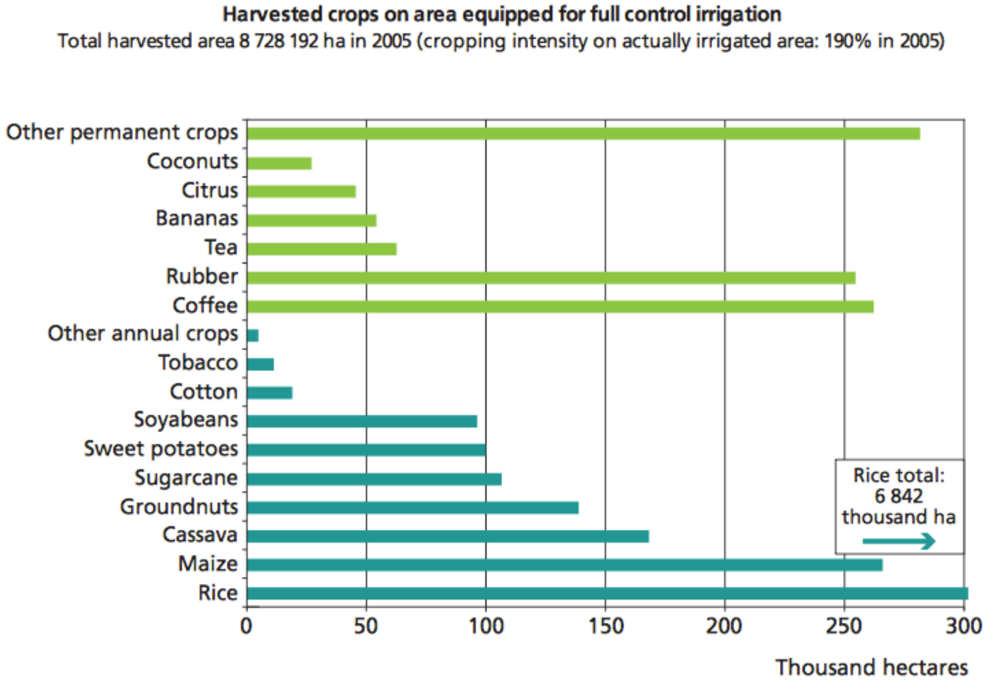


Figure A2.3. Irrigated crops in areas with full irrigation capabilities in Vietnam (Frenken 2012).

In Vietnam’s An Giang Province, farmers irrigate either through gravity flow or by pumping water from canals to their fields. The pumping is done via communal pumps (privately held, or commercial water service providers) or by individual pump users (Quicho 2013).

Institutions

The institutional framework in Vietnam can be divided into three main categories: national, provincial, and local. Irrigation on the national scale is primarily managed by the Ministry of Agriculture and Rural Development (MARD). MARD “has the primary responsibility for irrigation management. The water department within MARD and its associated institutes (including the Institute for Water Resources Planning), lead the planning and development for major agricultural infrastructure and development” (Kellogg 2009, p. 50).

The provincial counterparts to MARD are the Departments of Agriculture and Rural Development (DARDs). At the local level, there are Irrigation and Drainage Management Companies (IDMCs), water users' associations (WUAs), and some participatory irrigation management (PIMs) institutions (which are not legal entities but exist due to the MARD minister's decision). Nguyen (2010) described their responsibilities:

- MARD: Major irrigation infrastructure and development is organized by the MARD's Department of Water Resources and associated institutes. The MARD also oversees 12 corporations and 317 companies.
- DARDs: Responsible for supporting irrigation infrastructure in a smaller scale and assisting in technical aspects and planning irrigation and drainage schemes.
- IDMCs: Manage the headworks, main canals, pumping stations and sluices to take out water from main, primary and secondary canals.
- WUAs: Negotiate water supply agreements with IDMCs and are responsible for the operation and maintenance of pumping stations and other off-taking water structures applied to serve only one commune, company or individual farms. WUAs have responsibilities for commune and inter-commune branch canals and structures.
- PIMs: Operation differs according to the circumstances of the area where they are implemented. Small-scale structures are managed by the commune or the cooperatives themselves. These include structures that irrigate or drain areas within one commune. PIMS are active in 15–20 provinces, only supported by international donors.

Figure A2.4 describes the various authorities that have responsibilities in water and irrigation in Vietnam, illustrating the complexity of water-related management in Vietnam.

According to the Water Law, the government is responsible for the state management of water resources through the Ministry of Natural Resources and Environment (MONRE), which was transferred from MARD, while the service function of irrigation and rural water supply remains with MARD.

However, the National Water Resources Council, which manages water resources, is above the ministries and below the Prime Minister’s Office. At province and district level, the Provincial Peoples Committees, which are directly controlled by the central government, are responsible for implementation in their own jurisdiction.

Specific functions of water resources management and water use are allocated to ministries and non-line agencies are as follows:

- Ministry of Natural Resources and Environment is responsible for water resources management.
- Ministry of Agriculture and Rural Development is responsible for the management of flood and typhoon protection systems, hydraulic structures, wetland management, and rural water supply and sanitation.
- Ministry of Industry is responsible for the construction, O&M of hydropower facilities.
- Ministry of Construction is responsible for the spatial planning and construction of urban water supply, sanitation and drainage facilities.
- Ministry of Transport is responsible for the planning, construction and management of waterway transport systems.
- Ministry of Fisheries is responsible for the protection and exploitation of aquatic resources.
- Ministry of Health is responsible for the management of drinking water quality.
- Ministry of Planning is responsible for the planning and investment in the water and investment resources sector.
- Ministry of Finance is responsible for the development of policies on taxes and fees for water resources.

(FAO AQUASTAT 2013)

Figure A2.4. Institutions with authority in water and irrigation in Vietnam (FAO AQUASTAT 2013).

Irrigation costs

Irrigation fees were first established in 1984 in some provinces (e.g., Vinh Long in the Mekong River Delta) by Decree No. 43/2003/NĐ-CP. Fees were set based on criteria, including socioeconomics and water availability in the given region. For instance, in the Red River Delta, irrigation and drainage fees for pumping irrigation services cost $33–$50/ha in the spring and $30–$47 during the summer (FAO AQUASTAT 2011b). This changed when irrigation service fees were abolished in 2008, "dispossessing a high amount of the financial basis for the local Irrigation and Drainage Management Companies (IDMCs) and WUAs" (Kellogg 2009).

Prior to 2008, IDMCs in Quang Tri and Kon Tum reported receiving about $60/ha from irrigation service fees. As pointed out in an evaluation report prepared for the Asian Development Bank (2010), "the continued effectiveness of IDMCs and their services will therefore have to depend on government subsidies, which may not be adequate … . The abolition of the water fee has resulted in very little maintenance of irrigation schemes, which will affect the long-term sustainability of the sub-projects."

Kellogg (2009, p. xxvi) described the situation as follows:

> Strong irrigation development over many years has ensured food security and turned Viet Nam into a major exporter of rice. Irrigation management is steeped in tradition and now that irrigation water is provided free of charge, that tradition is further entrenched. Irrigation is now in effect a means of providing social services to most rural people - irrigation supply is inefficient, its infrastructure is old and dilapidated, totally reliant on state budgets and overseas development assistance to keep the systems going. Farmers still have little say in system management and with irrigation water now free, there is little incentive for farmers to get involved. Water supply is top down for paddy rice and not farmer driven. Crop diversification is difficult. For the future the [Government of Vietnam] will need to make hard decisions on the extent to which major reforms can be embraced to create, over time, an innovative and progressive irrigation sector.

Appendix 3. Expert survey

To establish a credible range for the diffusion rate of the technique of alternate wetting and drying (AWD), an expert survey was developed. Following are the key steps in the development, implementation, and analysis of the expert survey:

- Develop expert survey.
- Pre-test and obtain results from expert Ole Sander.
- Identify additional experts.
- Send to initial list of experts via email.
- Follow up if required, including finding new/appropriate email addresses.
- Document responses.
- Analyze and summarize results.
- Integrate results within impact scenarios.

Table A3.1 lists the experts who responded to the survey. The actual survey text follows the table.

Table A3.1. Experts who responded to the AWD survey

Expert Name	**Country of Expertise**	**Affiliation**	**Email address**
Dr. Ole Sander	Vietnam and Bangladesh	IRRI	b.sander@irri.org
Dr. Nghia	Vietnam	Institute of Policy and Strategy for Agriculture and Rural Development	tran.nghiadai99@gmail.com
Mai Van Trinh	Vietnam	IAE	maivantrinh@gmail.com
Le Van Chinh	Vietnam	DWR	chinhlv.tl@mard.gov.vn
Tim Russell	Bangladesh	IRRI	t.russell@irri.org

Estimating the national impact of rice GHG mitigation technologies

Expert opinion survey

This survey was sent to you as an expert in the field of research into rice production and/or greenhouse gas mitigation technologies focused on paddy rice production. Please answer as many of the questions you can, to the best of your ability. Even in the absence of specific empirical evidence, we ask that you provide the best guess estimate, based on your expert judgement.

The question focus on the alternate wetting and drying approach/technology. This is a priority technology for the purposes of the project being led by the Consultative Group on International Agricultural Research. Although we strongly encourage you to respond to the seven questions, questions 3 and 4 are especially important for our purposes.

When asked to provide estimates, you can either choose to provide the figure as ‘percentage land area’ or, if more intuitive to you, as ‘percentage farmers.’

Alternate Wetting and Drying

Question 1: What would be your best guess estimate of the percentage land area where this technology has already been adopted

1.a) In Vietnam?
1.b) In Bangladesh?

Question 2: What would be your best guess estimate of the percentage farmers that have already adopted this technology

2.a) In Vietnam?
2.b) In Bangladesh?

Question 3: What would be your best guess estimate of the percentage of land where it will be adopted in 5 years, in the absence of further efforts via formal Nationally Appropriate Mitigation Actions (NAMA) (i.e., under a ‘business-as-usual’ scenario)

3.a) In Vietnam?
3.b) In Bangladesh?

Question 4: What would be your best guess estimate of the percentage of farmers who will have adopted in 5 years, in the absence of further efforts via a formal NAMA (i.e., under a ‘business-as-usual’ scenario)

4.a) In Vietnam?
4.b) In Bangladesh?

Question 5: In your expert opinion, what is preventing farmers from adopting this technology?

5.a) In Vietnam?

5.b) In Bangladesh?

Question 6: In your expert opinion, what would be required in a NAMA to help increase the adoption of this technology?

6.a) In Vietnam?

6.b) In Bangladesh?

Question 7: How much more adoption do you believe could be achieved via your proposed solution(s) in question 6?

7.a) In Vietnam?

Please provide a best guess estimate in percentage land area where farmers would adopt

Please provide a best guess estimate in percentage farmers adopting

7.b) In Bangladesh?

Please provide a best guess estimate in percentage land area where farmers would adopt

Please provide a best guess estimate in percentage farmers adopting

6. References

[ADB] Asian Development Bank. 2010. Viet Nam: Rural Infrastructure Sector Project Performance Evaluation Report. Reference Number: PPE:VIE 2010-31. (Available from: http://www.oecd.org/countries/vietnam/47170704.pdf)

Alam MS, Islam MS, Salam MA, Islam MA. 2009. Economics of alternate wetting and drying method of irrigation: evidences from farm level study. *The Agriculturists* 7(1&2): 82–89.

Ali MA, Hoque MA, Kim, PJ. 2013. Mitigating global warming potentials of methane and nitrous oxide gases from rice paddies under different irrigation regimes. *Ambio* 42: 357–68. (Available from: http://dx.doi.org/10.1007/s13280-012-0349-3)

Applied GeoSolutions. 2013. *Design of a Monitoring, Reporting and Verification System for Rice GHG Emissions in Vietnam – The AILEG Project.* Prepared for the Office of Economic Policy, Bureau of Economic Growth, Education and Environment, U.S. Agency for International Development. October 2013. (Available from: http://pdf.usaid.gov/pdf_docs/PA00KSSR.pdf)

Azeem M, Sharif M, Shafiq M, Ahmad Z, Longmire J. 1989. *Wheat varietal diffusion in the irrigated Punjab: results from 1988-89*. PARC/CIMMYT Collaborative Programme: AERU Faisalabad Staff Paper No. 89-1. (Available from: http://repository.cimmyt.org/xmlui/bitstream/handle/10883/3850/19527.pdf) (Accessed on May 17, 2015)

Basak JK. 2011. *Impacts of increasing production costs on rice price: implications for food security*. Dhaka, Bangladesh: Unnayan Onneshan—The Innovators.

Bockel L, Touchemoulin O. 2011. *The low carbon agricultural support project (LCASP) in Vietnam - carbon balance appraisal with the Ex-Ante Carbon Balance Tool*. FOA EASYPol Resources for policy making document.

Bong BB.1999. *Bridging the rice yield gap in Vietnam*. FAO Corporate Document Repository. (Available from: http://www.fao.org/docrep/003/x6905e/x6905e0e.htm) (Accessed on June 8, 2015)

Erenstein O. 2010. Triangulating technology diffusion indicators: Zero tillage wheat in South Asia's irrigated plains. *Experimental Agriculture* 46(3): 293–308.

[FAO] Food and Agriculture Organization of the United Nations. AQUASTAT 2011a. Irrigation in Southern and Eastern Asia in figures – AQUASTAT Survey – Bangladesh report. (Available from: http://www.fao.org/nr/water/aquastat/countries_regions/bgd/index.stm)

[FAO] AQUASTAT 2011b. Irrigation in Southern and Eastern Asia in figures – AQUASTAT Survey – Vietnam report. (Available from: http://www.fao.org/nr/water/aquastat/countries_regions/VNM/index.stm)

[FAO] AQUASTAT. 2013. UN-Water Country Brief: Vietnam. Geneva: UN-Water. (Available from: http://www.unwater.org/fileadmin/user_upload/unwater_new/docs/Publications/VNM_pagebypage.pdf

Faruki MRI, Ali MH, Saha RC, Roy AK. 2011. Effect of water saving technology through alternate wetting and drying for boro rice cultivation. *Journal of Agroforestry and Environment* 5(1):11–14.

Frenken K. 2012. Irrigation in Southern and Eastern Asia in Figures: AQUASTAT survey in figures FAO Water Report 37. Rome: FAO. (Available from: http://www.fao.org/docrep/016/i2809e/i2809e.pdf)

[GoB] Government of Bangladesh. 2012. National Communication to the UNFCCC. (Available from http://unfccc.int/resource/docs/natc/bgdnc2.pdf)

Government of The Gambia. 2015. *NAMA design document for rural electrification with renewable energy in the Gambia*. The Gambia: United Nations Development Programme. (Available from: http://www.undp.org/content/dam/undp/library/Environment%20and%20Energy/MDG%20Carbon%20Facility/The%20Gambia%20NAMA%20final%202.pdf)

Government of the Republic of Namibia. 2015. *Nationally appropriate mitigation action: rural development in Namibia through electrification and renewable energy*. Namibia: United Nations Development Programme. (Available from:

http://www.undp.org/content/dam/undp/library/Environment%20and%20Energy/MDG%20Carbon%20Facility/NAMIBIA_final%20NAMA.pdf)

Government of the Republic of the Philippines. 2014. *Design of an adaptation oriented NAMA option for the rice sector in the Philippines*. Philippines: Department of Environment and Natural Resources.

Government of the Republic of the Philippines. 2015. *Adaptation and mitigation initiatives in Philippine rice cultivation.* Philippines: United Nations Development Programme. (Available from: http://www.undp.org/content/dam/undp/library/Environment%20and%20Energy/MDG%20Carbon%20Facility/AMIA%20Philippines.pdf)

[GoV] Government of Vietnam. 2014. National Communication to the UNFCCC. (Available from: http://unfccc.int/resource/docs/natc/vnmnc02.pdf)

Ha TT. 2014. *Vietnam low carbon rice project –VLCRP Triple wins: economic, environment & social development.* Vietnam: Australian Government's Aid Program.

Karim MR, Alam MM, Ladha JK, Islam MS, Islam MR. 2014. Effect of different irrigation and tillage methods on yield and resource use efficiency of boro rice (*Oryza sativa*). *Bangladesh Journal of Agricultural Research* 39(1): 151–163.

Kellogg Brown & Root Pty Ltd. 2009. Socialist Republic of Viet Nam: Water Sector Review. Technical assistance consultants report. Asian Development Bank. (Available from: http://www.adb.org/sites/default/files/project-document/65077/40621-vie-tacr.pdf)

Krupnik TJ, McDonald AJ, Schulthess U. 2013. Turning on the 'off season' to forgo the fallow in South-western Bangladesh: An ex-ante method to target decentralized surface water irrigation. Kathmandu, Nepal: International Maize and Wheat Improvement Centre (CIMMYT).

Kürschner E, Henschel C, Hildebrandt T, Jülich E, Leineweber M, Paul C. 2010. *Water saving in rice production–dissemination, adoption and short term impacts of alternate wetting and drying (AWD) in Bangladesh.* Berlin: Humboldt-Universität zu Berlin.

Lampayan RM, Rejesus RM, Singleton GR, Bouman BA. 2015. Adoption and economics of alternate wetting and drying water management for irrigated lowland rice. *Field Crops Research* 170: 95–108.

Meier S. Unpublished. 2005/6 data and results, as referenced in Lampayan RM, Rejesus RM, Singleton GR, Bouman BA. 2015. Adoption and economics of alternate wetting and drying water management for irrigated lowland rice. *Field Crops Research* 170: 95–108.

Minh LN. 2013. Rice miracle or mirage: Who gains from high prices in Vietnam? Blogpost on Oxfam America website. (Available from: http://politicsofpoverty.oxfamamerica.org/2013/10/rice-miracle-or-mirage-who-gains-from-high-prices-in-vietnam/) (Accessed on October 15, 2015)

[MoA] Ministry of Agriculture of Bangladesh**.** 2008. *Minor irrigation survey report 2007-08.* Survey and Monitoring Project, BADC, October, Dhaka, Bangladesh.

Loevinsohn M, Sumberg J, Diagne A, Whitfield S. 2013. Under what circumstances and conditions does adoption of technology result in increased agricultural productivity? London: Institute of Development Studies, Department for International Development. (Available from: http://www.ids.ac.uk/publication/under-what-circumstances-and-conditions-does-adoption-of-technology-result-in-increased-agricultural-productivity-a-systematic-review) (Accessed on May 23, 2015)

Narayan T, Belova A. 2013. *Achieving low emissions growth for rice cultivation in Vietnam: a role for behavioural constraints*. Proceedings of the Agricultural and Applied Economics Association 2014 Annual Meeting held in Minneapolis, Minnesota, 27–29 July 2014.

Nargis F, Miah TH, Khanam TS, Sarwer RH. 2009. *Profitability of MV boro rice production under shallow tubewell irrigation system in some selected areas of Tangail District*. *Progressive Agriculture* 20: 237–244.

Nguyen TPL. 2010. Legal Framework of the Water Sector in Vietnam ZEF Working Paper Series 52. Zentrum für Entwicklungsforschung. pp. 1–111. (Available from: http://www.zef.de/fileadmin/webfiles/downloads/zef_wp/wp52.pdf)

Pandey A, Vu DQ, Bui TPL, Mai TLA, Jensen LS, de Neergaard A. 2014. Organic matter and water management strategies to reduce methane and nitrous oxide emissions from rice paddies in Vietnam. *Agriculture, Ecosystems & Environment* 196: 137–146.

Price AH, Norton GJ, Salt DE, Ebenhoeh O, Meharg A, Meharg C, Islam MR, Sarma R, Dasgupta T, Ismail AM, McNally KL, Zhang H, Dodd IC, Davies WJ. 2013. Alternate wetting and drying irrigation for rice in Bangladesh: Is it sustainable and has plant breeding something to offer? *Food and Energy Security* 2(2): 120–129. (Available from: http://onlinelibrary.wiley.com/doi/10.1002/fes3.29/full)

Richards M, Sander BO. 2014. *Alternate wetting and drying in irrigated rice: Implementation guidance for policymakers and investors*. Practice Brief on Climate-Smart Agriculture. (Available from https://cgspace.cgiar.org/bitstream/handle/10568/35402/info-note_CCAFS_AWD_final_A4.pdf) (Accessed on May 19, 2015)

Sander BO, Wassmann R, Siopongco JDLC. 2016. *Mitigating Greenhouse Gas Emissions from Rice Production through Water-Saving Techniques: Potential, Adoption and Empirical Evidence*. Wallingford: CABI. (Available from: http://www.cabdirect.org/abstracts/20153417471.html;jsessionid=C8723436B559085C2C152E183EE1D363)

Sandin S. 2005. Present and future methane emissions from rice fields in Đông Ngạc commune, Hanoi, Vietnam. Göteborg University, Department of Physical Geography, 41 pp. (Available from: http://gvc.gu.se/digitalAssets/1347/1347932_b446.pdf)

Sattar MA, Rashid MA, Hassan MN, Molla HR, Khan AK, Parveen S, Roy D, Mahamud H. 2009. *AWD technology for water saving in boro rice production for the selected locations*. In: Conference proceedings, AWD national workshop, Dhaka, Bangladesh.

Quicho ED. 2013. *Are there socio-economic benefits of adopting AWD in water-abundant rice areas in An Giang Province, Vietnam?* In: SSD Division Seminar 26 July 2013. (Available from: http://www.scribd.com/doc/185923784/Are-there-socio-economic-benefits-of-adopting-AWD-in-water-abundant-rice-areas-in-An-Giang-Province-Vietnam#scribd) (Accessed on April 19, 2015)

Tsusaka TW, Kajisa K, Pede VO, Aoyagi K. 2015. Neighborhood effects and social behavior: The case of irrigated and rainfed farmers in Bohol, the Philippines. *Journal of Economic Behavior & Organization* 118: 227–246.

[UNFCCC]. United Nations Framework Convention on Climate Change. No date. *Emissions summary for Bangladesh*. Bangladesh: United Nations Climate Change Secretariat. (Available from: (https://unfccc.int/files/ghg_data/ghg_data_unfccc/ghg_profiles/application/pdf/bgd_ghg_profile.pdf) (Accessed on April 14, 2015)

Water and Sanitation Program. 2009. Bangladesh Water Utilities Data Book 2006–07: Benchmarking for Improving Water Supply Delivery. Report. (Available from: http://www.wsp.org/sites/wsp.org/files/publications/Bangladesh_Utilities_Report.pdf)

Wiggins S, Keats S. 2014. *Rural wages in Asia*. London: Overseas Development Institute.

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