Trucost Methodology Report

Valuation of Natural Capital Costs and Benefits for the TEEB Rice Study

Version 3.0

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Guide to Readers

This document describes the methodology applied by Trucost to estimate the monetary value of the positive and negative impacts of rice cultivation. This document should be read in conjunction with the TEEB Rice project final report and the Trucost Natural Capital Valuation Methodology, which details the methodologies underlying the valuation of final human health, economic and ecosystem changes.

All prices are expressed in 2015 price year US dollars and a Purchasing Power Parity adjustment was applied based on data from the World Bank (2015b).

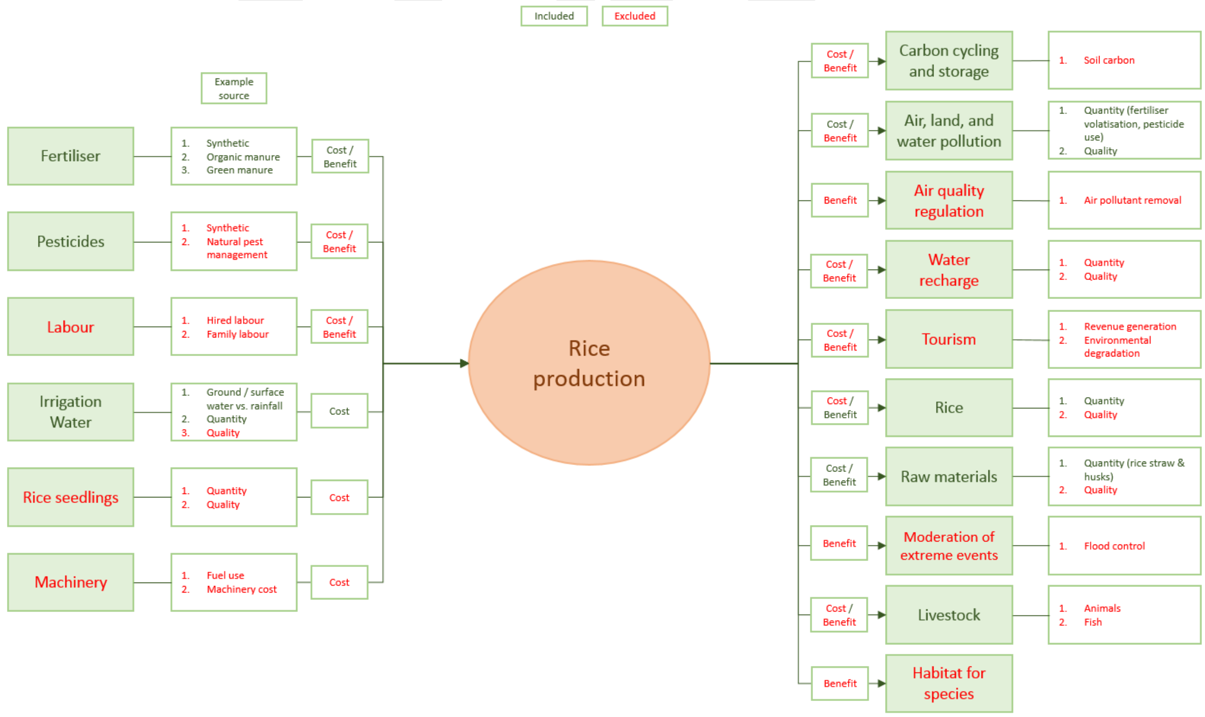
1. Introduction

This document describes the methodology applied by Trucost to estimate the monetary value of the positive and negative impacts of rice cultivation. In some cases this involves the direct application of a valuation coefficient (such as the producer price per tonne of rice) to a biophysical data point collected in the literature review (such as the rice yield in tonnes). However, in many cases additional biophysical modelling is necessary to estimate the health, ecological or economic change resulting from a particular practice or biophysical change, which can then be valued in monetary terms. For example, valuation of the eutrophication potential of chemical or organic fertilisers applied to rice fields requires not only biophysical data on the quantity of fertiliser applied, but a model to estimate the nutrient balance of the rice production system and to quantify the transfer of eutrophying pollutants to surface water. This methodology document describes the assumptions underlying the biophysical modelling applied to quantify the biophysical endpoints for valuation. The Trucost Natural Capital Valuation Methodology describes the detailed methodology applied to value the impact of the biophysical endpoints on health, ecosystems and/or the economy.

The methodology document also describes the methodology and data sources used to value realised economic costs and benefits (such as income from the sale of rice) based on market prices.

Figure 1 provides an overview of the biophysical processes occurring in rice production systems that have been included and excluded from the monetary valuation process. Please note that this representation is not exhaustive and that the inclusion of processes in the monetary valuation was constrained by data availability.

Figure 1: Rice Natural Capital Impacts and Dependencies Valuation - Overview of Included and Excluded Processes



As shown in Figure 1, a diverse range of costs and benefits are included in the analysis. The monetary valuation analysis considers two broad categories of costs and benefits:

- **Realised Economic Benefits and Costs:** This category includes costs and benefits that are realised in the market due to changes in yield and input requirements, or by recovering useful by-products of the rice cultivation system. These costs and benefits typically accrue primarily to the rice farmer and their local community, in the form of increased income or reduced expenditure on inputs.
- **Hidden Economic Benefits and Costs:** This category includes costs and benefits that accrue to society more broadly in the form changes in health risk factors and ecosystem services associated with ecosystem quality in the environments nearby and distant to the rice field. This includes changes in adverse health and ecosystem impacts associated with air, land and water pollution, water resource depletion, climate change and eutrophication. These costs and benefits are typically not fully accounted for in the market prices of the inputs and outputs of the rice production system.

The distinction between realised and hidden costs and benefits is not exclusive. Some hidden costs will impact on both the farmer and society more broadly, and realised benefits can also impact upon national economies with broader effects on society. However, the distinction between realised and hidden benefits is useful as a means of illustrating the trade-offs inherent in different rice production practices and systems.

2. Hidden Natural Capital Costs

This section describes the methodologies applied to value the hidden natural capital costs of rice cultivation practices in monetary terms. Key natural capital impacts included in this study include pesticide and herbicide emissions to land and water; water depletion; nutrient run-off to water; air pollutant emissions; and greenhouse gas emissions from fertiliser and crop management.

2.1. Pesticide and Herbicide Emissions to Land and Water

The Trucost Natural Capital Valuation Methodology (Air, Land and Water Pollutants) provides monetary valuation coefficients for estimating the health and ecosystem impact per kilogram of pesticide and herbicide active ingredient applied to agricultural soil. The biophysical data was first converted from litres per hectare to kilograms of active ingredient per hectare (where necessary) using the density of the pesticide. The valuation coefficients were then applied to estimate the monetary impact of pesticide and herbicide inputs per hectare. This process is summarised in the formula below:

$V_p = P_l \times P_d \times VC$

Where;

- V_p is the monetary value of the impact of pesticides or herbicides applied per hectare (US$, 2015 price year).
- P_l is the volume of pesticide or herbicide active ingredient applied per hectare **[Study specific assumption]**.
- P_d is the density of the pesticide (or herbicide) in kilograms per litre **[Global assumption]**.
- VC is the Trucost valuation coefficient for the pesticide or herbicide per kilogram applied to agricultural soil **[Country specific assumption]**.

A total of 25 unique pesticides and herbicides were identified as inputs to rice cultivation in the studies included in the literature review. The valuation methodology considers the effect of each compound on human health, terrestrial ecosystems, marine ecosystems and freshwater ecosystems. Table 1 details which aspects of ecosystem and human health damage are included in the valuation of each compound.

Table 1: Impacts Included in Trucost Valuation of Pesticide and Herbicide Ecosystem and Health Effects

Compound	Freshwater	Marine	Terrestrial	Health
2,4-Dichlorophenoxyacetic Acid	✓	✓	✓	✓
Bentazone	✓	✓	✓	✓
Butaclor	✓	✓	✓	X
Cipermetrin	✓	✓	✓	✓
Clomazone	✓	✓	✓	X
Propionic acid (proxy for **Cyhalofop-butyl**)*	✓	✓	✓	X
Dalapon	✓	✓	✓	X
Dazomet	✓	✓	✓	X
Dimetoate	✓	✓	✓	✓

Ethoxysulfuron	X	X	X	X
Fenoxaprop	√	√	√	X
Furadan	√	√	√	√
Glyphosate	√	√	√	√
2-Thiohydantoin (proxy for **Imazapic**)*	√	√	√	X
I**midaclorpid**	X	X	X	X
B**ensulfuron methy**	X	X	X	X
Ordram (molinate)	√	√	√	√
Oxadiazon	√	√	√	X
Oxifluorfen	√	√	√	X
Pendimethalin	√	√	√	√
Sulfadimethoxine (proxy for **Penoxsulam**)*	√	√	√	X
Pretilachlor	√	√	√	√
Propanil	√	√	√	√
Safaner	√	√	√	√
Triazofos	√	√	√	X

Three compounds identified in the literature were not included within the toxicity models that underpin the Trucost valuation methodology. In these cases, a proxy has been selected which falls within the same pesticide class or has a similar mode of action, to represent the missing compound (these cases are denoted with an asterisk in the table above). No suitable proxy could be identified for Ethoxysulfuron, Imidacloprid and Bensulfuron methyl and hence the impacts of these compounds could not be valued.

Impacts on Ecosystems

The ecosystem impact valuations are based on continental scale modelling of the dispersion of pesticides and herbicides applied to agricultural soil and a country specific valuation of the complement of ecosystems contained within each country that are affected by each pesticide or herbicide. This method is described in further detail in the Trucost Natural Capital Valuation Methodology.

Impacts on Human Health

The human health impact valuation is based on continental scale modelling of the dispersion of pesticides and herbicides and their health impact expressed in Disability Adjusted Life Years (DALY). Each DALY is valued based on a global median Value of a Life Year (VOLY) calculated via a method taking account of income elasticity, as described in the Trucost Natural Capital Valuation Methodology.

2.2. Water Consumption

The Trucost water consumption methodology estimates a country specific monetary value for the health and ecosystem impact per cubic metre of water used for rice cultivation or any other purpose. These valuation coefficients were applied to the total water input to the rice field (water cost) where this was reported in the original studies identified in the literature review.

Where the original studies did not provide data on the quantity of water applied to the rice field, water consumption costs were not valued. This is because the outcome would rely on non-site specific data that is not correlated with other parameters measured in the original study (such as yield). Water inputs were estimated for studies not reporting water data as an input to the water balance calculation applied in the calculation of run-off of eutrophying pollutants as described in Section 2.3.

The valuation of water consumption is calculated using the formula below:

$V_{wc} = W \times VC$

Where;

- V_{wc} is the monetary value of water consumed ($US, 2015 price year).
- W is the volume of water consumed over the growing period in cubic meters.
- VC is the Trucost country specific valuation coefficient for water consumption.

Impacts on Ecosystems

The impacts on ecosystems due to water consumption included in this methodology are limited to the effect of water scarcity on net primary productivity of ecosystems. Net primary productivity is used as a proxy for ecosystem health, which is in turn related to the capacity of ecosystems to deliver ecosystem services. Country specific valuations are estimated based on the estimated water scarcity in each country (based on data from the World Resources Institute – See the Trucost Natural Capital Valuation Methodology for further detail) and country specific values for the complement of ecosystems contained within each country.

Impacts on Human Health

The impacts on human health due to water consumption included in this methodology include those linked to the lack of water for irrigation of agriculture for food production and the lack of access to safe water for consumption and sanitation. Country specific valuation coefficients are estimated based on the estimated water scarcity in each country (based on data from the World Resources Institute – See the Trucost Natural Capital Valuation Methodology for further detail) and a global value per DALY lost.

2.3. Fertiliser Use

Emissions to air and water associated with chemical and organic fertiliser use are considered in the monetisation analysis. The methodology applied includes an additional biophysical modelling step (in addition to the Trucost Natural Capital Valuation Methodology (Eutrophying Pollutants)) to take account of differences in fertiliser run-off at the farming practice level.

2.3.1. Nutrient Emissions to Water (Run-Off)

Biophysical Modelling

Excess application of synthetic or organic nitrogen (N) or phosphorous (P) fertilisers to agricultural land is an important cause of eutrophication in nearby water bodies. Eutrophication can affect rivers, lakes, reservoirs and coastal waters. The enriched waters, when warmed in summer, can produce blooms of algae, which have short lifespans, and decay via a process that consumes dissolved oxygen in the water. These algae blooms can be so severe that all available dissolved oxygen is consumed resulting in hypoxia, which kills fish and other organisms (Anderson et al., 2002). Harmful algae blooms (HABs) occur when toxic algae grows in the water (Ibid). These blooms can give off an unpleasant smell, reduce water clarity and harm the health of animals that consume the water. Algae blooms can occur in both inland and coastal waters.

Nitrate run-off from agricultural fields to surface water, or leaching to groundwater, can also pose health risks for humans where nitrate concentrations exceed critical thresholds. The World Health Organisation (2011) recommends a limit on nitrate and nitrite concentration in drinking water of 50mg/l and 3mg/l respectively.

In order to value the eutrophication and drinking water contamination impacts of agricultural fertiliser use, it is necessary to estimate the quantity of nitrogen and phosphorous that is transported from the field via run-off and leaching. Combined run-off and leaching has been estimated by, first estimating the nitrogen and phosphorus balance of the rice field over the growing period, then calculating the water balance, and finally by calculating the straight-line distance to the nearest waterbody using GIS maps provided by the Global Lakes and Wetland Database and HydroSHEDS river networks (Lehner & Döll, 2004; USGS, 2008). It is assumed that the proportion of excess N or P (positive balance) that is transported to water bodies, through runoff or leaching to groundwater, is correlated with the proportion of water inflows to the rice field that is not utilised by the crop (water use efficiency (Ei)). This approach is based on the life cycle assessment methodology for rice production in Thailand described by Koch and Salou (2015) as part of the AGRIBALYSE program.

Where the N or P balance is negative, the deficit is assumed to be supplied by the nutrient content of the soil and therefore no run-off is assumed to occur. The depletion of soil nutrient content is valued as a hidden natural capital cost as described in Section 2.7.

Nitrogen Balance Calculation

Figure 2 provides an overview of the nitrogen balance calculation. The nitrogen balance calculation is based upon the following principles:

- Nitrates are the primary components of a surplus nitrogen balance as crops are assumed to primarily consume N in the form of ammonium (Koch and Salou, 2015).
- Most nitrate losses occur through leaching and drainage, and the remainder (e.g. lost through erosion) is assumed to be negligible. A study of rice production in Thailand by Pathak et al. (2004) found that losses to leaching and drainage were split 80% and 20% respectively.

- Leaching and drainage is assumed to be dependent on the proportion of water not utilised by the crop, the water use efficiency. Thus the quantity of nitrate leached or drained to water bodies (Nw) is calculated as:

  $Nw = N_{(nitrates)} \times (1 - Ei)$

  Where $N_{(nitrates)}$ is the value of the nitrogen balance if positive (i.e. surplus nitrogen) and (1-Ei) represents the excess water applied to the field that is not utilised by the crop.

Figure 2: Nitrogen Balance Calculation

Nitrogen (Input)	-	**Nitrogen (Output)**	-	**Nitrogen (Soil)**	=	**Nitrogen Balance**
▪ Fertiliser N input ▪ Precipitation N input ▪ Irrigation N input ▪ Mineralisation of organic matter		▪ Net export in crop biomass ▪ N_2O, NO, NH_3 to air ▪ N_2 emission to air ▪ N immobilisation ▪ N (nitrate) leaching ▪ N (nitrate) drainage		▪ Assumed nil		

Nitrogen *inputs* are calculated as follows (the granularity of the assumptions applied for each input is shown in brackets):

- *Fertiliser N Input:* The total N content of synthetic and organic fertilisers applied to the rice paddy over the growing period (kg per Hectare). **(Practice specific assumption)**
- *Precipitation N Input*: N input from precipitation was assumed to be constant at 2.04E-06 kg per mm of rainfall over the growing period (Koch and Salou, 2015). **(Global assumption)**
- *Irrigation N Input*: N input from irrigation water was assumed to be constant at 3.210E-07 kg per mm of irrigation water input over the growing period (Koch and Salou, 2015). **(Global assumption)**
- *Mineralisation of Organic Matter*: It was assumed that in stable rice production over several years, soil organic matter dynamics would be stable with mineralisation equal to immobilisation. Thus the net loss or gain from N immobilisation and mineralisation was assumed to be zero (Koch and Salou, 2015). **(Global assumption)**
- *Other N inputs*, such as symbiotic nitrogen fixation (beyond that directly incorporated through organic fertilisation) or inputs from groundwater (or than that applied via irrigation), were assumed to be negligible as per Pathak et al (2004). **(Global assumption)**

Important Note: Dry deposition of nitrogen from the air is not included in the nitrogen balance as per Koch and Salou (2015).

Nitrogen *outputs* are calculated as follows (the granularity of the assumptions applied for each input is shown in brackets):

- *N Exported in Crop Biomass:* The primary N output is the export of nutrients contained within the harvested crop, including the N content of the rice grain, husk and straw. Where rice straw remains in the field, N is assumed to be returned to the system. Total N and P removed by rice crops was estimated based on a study by Ernst and Mutert (1995) which calculated the N and P content (kg) per tonne of rice grain and straw in fertilised and unfertilised crop systems (Table 2). An average of the fertilised and unfertilised values was used to estimate N and P export for all study countries and practices. **(Practice specific yield / Global nutrient content assumption)**

Table 2: Nitrogen and Phosphorus Export in Rice Harvest (Adapted from Ernst and Mutert (1995))

	Without Fertilizer (kg/Tonne)		With Fertilizer (kg/Tonne)		Average (kg/Tonne)	
	Straw	Grain	Straw	Grain	Straw	Grain
Nitrogen	6.43	10.00	9.15	14.59	7.79	12.30
Phosphorus	0.71	2.94	0.61	2.65	0.66	2.80

- *N Volatilisation from Fertiliser*: N losses to volatilisation were calculated separately for nitrous oxide (N_2O), ammonia (NH_3) and nitric oxide (NO) using the formulas described in Box 1 below. NH_3 emissions are dependent on the type of N fertiliser applied to the field. Where primary data was not available for the breakdown of N fertilisers applied, a regional average breakdown was applied based on International Fertiliser Association global apparent fertiliser consumption statistics for 2013 (IFA, 2015). **(Global assumption)**
- *N_2 Emissions from Denitrification*: N_2 emissions from denitrification are assumed to occur at a rate of 0.09 kg per kg of N applied in chemical fertilisers per hectare based on Brentrup et al (2000). **(Global assumption)**
- *Immobilisation*: N losses to immobilisation are assumed to be negligible on the basis that immobilisation and mineralisation will be equal over time in a stable crop system (Koch and Salou, 2015). **(Global assumption)**
- *Nitrogen losses to soil (*Nsoil) was assumed to be negligible in stable crop production systems where soils have stable long term N content (Koch and Salou, 2015). **(Global assumption)**

Box 1: Calculation of Nitrogen Volatilisation from Chemical Fertilisers (Koch and Salou, 2015)

N_2O Volatilisation from Fertiliser

$N\text{-}N_2O = (0.0025 \times Nf) + (0.26 \times D/117)$

Where:

- Nf is the total N content of chemical fertilizers applied in kg per hectare.
- 0.0025 is the average emission factor from fertilization.
- D is the duration of the growing period **(Country Specific Assumption)** (FAO, 2012).
- 0.26 N $kg.ha^{-1}$ is the mean base level emission of $N\text{-}N_2O$ during the growing period.

Note: This model does not account for intermittent flooding conditions where nitrification-denitrification is likely to produce increased N_2O emissions (Koch and Salou, 2015).

NH_3 Volatilization from Fertilizer

$N\text{-}NH_3 = (0.22 \times N\text{-}U \times 0.46) + (N\text{-}AB \times 0.33) + (N\text{-}AS \times 0.22) + (N\text{-}AP \times 0.05) + (N\text{-}Other \times 0.02) + (B \times D/365)$

Where:

- N-U is the N content of urea fertiliser applied (kg/ha).
- N-AB is the N content of ammonium bicarbonate fertiliser applied (kg/ha).
- N-AS is the N content of ammonium sulphate fertiliser applied (kg/ha).
- N-AP is the N content of ammonium phosphate fertiliser applied (kg/ha).

- N-Other is the N content of other fertilisers (including ammonium nitrate, calcium ammonium nitrate, triple superphosphate and potash) applied (kg/ha).
- B is the baseline emission of ammonia at 1.5 kg per hectare per annum.
- D is the duration of the growing period **(Country Specific Assumption)** (FAO, 2012).

Note: The calculation of ammonia emissions from urea assumes that 30% is applied during plot preparation, 30% after planting and 40% on the formation of the panicle (Koch and Salou, 2015).

NO Volatilisation from Fertiliser

N-NO = (0.0013 x Nf) + (0.57 x D/365)

Where:

- Nf is the N content of chemical fertilisers applied during the growing period (kg/ha).
- 0.0013 is the mean emission factor for fertilization.
- D is the duration of the growing period **(Country Specific Assumption)** (FAO, 2012).
- 0.57 is the mean N-NO base level emissions during the year (kg.ha-1)

The remaining N is assumed to be in the form on NO_3- and will be transported to water bodies through leaching and drainage in proportion with the fraction of water applied to the field, but not utilised by growing plants. This fraction is calculated as per the water balance calculation below.

Phosphorus Balance Calculation

The phosphorous balance is calculated in a similar way to the nitrogen balance, but with fewer inputs and outputs as shown in Figure 3.

Figure 3: Phosphorus Balance Calculation

Phosphorus (Input)	-	**Phosphorus (Output)**	-	**Phosphorus (Soil)**	=	**Phosphorus Balance**
▪ Fertiliser P input ▪ Precipitation P input ▪ Irrigation P input ▪ Mineralisation of organic matter		▪ Net export in crop biomass ▪ N immobilisation ▪ P leaching ▪ P drainage		▪ Assumed Nil		

Phosphorus *inputs* are calculated as follows:

- *Fertiliser P Input:* The total P content of synthetic and organic fertilisers applied to the rice paddy over the growing period (kg per hectare). **(Practice specific assumption)**
- *Precipitation P Input*: P input from precipitation was assumed to be constant at 4.50E-07 kg per mm of rainfall over the growing period (Koch and Salou, 2015). **(Global assumption)**
- *Irrigation P Input*: P input from irrigation water was assumed to be constant at 1.25E-06 kg per mm of irrigation water input over the growing period (Koch and Salou, 2015). **(Global assumption)**
- *Mineralisation of Organic Matter*: It was assumed that in stable rice production over several years, soil organic matter dynamics would be stable with mineralisation equal to immobilisation. Thus the net loss or gain from P immobilisation and mineralisation was assumed to be zero (Koch and Salou, 2015). **(Global assumption)**

Phosphorus *outputs* are calculated as follows:

- *P Exported in Crop Biomass:* The primary P output is the export of nutrients contained within the harvested crop, including the P content of the rice grain, husk and straw. Where rice straw remains in the field, P is assumed to be returned to the system. Total N and P removed by rice crops was estimated based on a study by Ernst and Mutert (1995) which calculated the N and P content (kg) per tonne of rice grain and straw in fertilised and unfertilised crop systems (Table 2). **(Practice specific yield / Global nutrient content assumption)**

- *Immobilisation*: P losses to immobilisation were assumed to be negligible on the basis that immobilisation and mineralisation will be equal over time in a stable crop system (Koch and Salou, 2015). **(Global assumption)**
- *Losses to soil* were assumed to be negligible in stable crop production systems where soils have stable long term P content (Koch and Salou, 2015). **(Global assumption)**
- *Losses to soil erosion* were assumed to be negligible since rice paddies are typically flat (or terraced) and protected from water overflow by dykes (Koch and Salou, 2015). **(Global assumption)**

The remaining P is assumed to be transported to water bodies through leaching and drainage in proportion with the fraction of water applied to the field but not utilised by growing plants. This fraction is calculated as per the water balance calculation shown below.

Water Balance Calculation

The water balance is calculated as follows:

$Ei = ET / (P + I)$

Where:

- Ei is the proportion of water inflows to the rice field that is not utilised by the crop, otherwise known as water use efficiency.
- ET is the average evapotranspiration (m^3) over the growing period estimated based on country average annual evapotranspiration (CGIAR-CSI, n.d.). **(Country specific assumption)**
- P is precipitation (m^3) over the growing period based on practice specific data derived from the literature review **(Practice specific assumption)** or estimated based on country specific monthly average precipitation (World Bank, 2015a) over the typical rice growing period in each country (FAO, 2012) **(Country specific assumption)**. Precipitation over the growing period was calculated by mapping the monthly average precipitation for each study country to the median growing period in each agro-ecological zone in each country based on FAO Crop Calendar (FAO, 2012). A simple average for all agro-ecological zones in each country was taken and used to represent the average precipitation over the growing period.
- I is the irrigation water input (m^3) over the growing period. Total irrigation water input was sourced from the input studies where reported **(Practice specific assumption)**, or estimated by subtracting country average precipitation from the reported total water applied over the growing period **(Country specific assumption)**. Where no data were available, irrigation water input was assumed to be 150 m^3 per hectare per day (Tuong and Bouman, 2003) **(Global assumption)** over the average growing period in each country (FAO, 2012). **(Country specific assumption)**

Important Methodology Notes

The following additional assumptions were made in calculating the nitrogen, phosphorus and water balances:

- Where rice straw was identified as an organic input but the quantity was not specified, the quantity was assumed to be equivalent to the rice straw yield reported in the study (if available). **(Global assumption)**
- Green manure inputs (including A. afraspera, A. nilotica, S. rostrate and azolla) were assumed to provide nitrogen input only as insuficient data was available on the phosphorus content of these crops. **(Global assumption)**
- Where rice straw compost was used as an organic input the nutrient content was assumed to be equivalent to that of unprocessed rice straw. This may understate the nutrient supplement provided by

compost since the nutrients may be more concentrated and available to the plants when applied as compost rather than raw rice straw (IRRI, n.d.). This approach was chosen as a conservative option. **(Global assumption)**

- The nutrient content of rice straw biochar was calculated based on Atland and Locke (2013). **(Global assumption)**
- Organic fertiliser inputs were treated as equivalent to chemical fertiliser inputs for the purposes of the nutrient balance calculation. That is, both chemical and organic nitrogen and phosphorous inputs contribute to the total nutrient input from fertiliser. **(Global assumption)**
- Where the nitrogen or phosphorus balance was less than zero, no leaching or run-off was assumed to occur, however the depletion of soil nitrogen and phosphorus was valued based on the cost of fertiliser (urea for nitrogen and triple superphosphate for phosphorus) required to replace the lost nutrients. **(Global assumption)**
- Where the water balance was zero, no run-off or drainage was assumed to occur since water was assumed to be necessary to mediate these processes. **(Global assumption)**

Impacts on Ecosystems

The Trucost Natural Capital Valuation Methodology provides valuation coefficients for the impact of nitrogen and phosphorus emissions to water and was applied to value the impact of fertiliser use on ecosystems, water quality and water treatment costs. This valuation is based on the estimated change in secchi depth (a measure of water clarity and eutrophic state) per kilogram of nitrogen or phosphorus deposited in a hypothetical lake constructed for each country based on country specific data. The change in secchi depth is valued based on a hedonic pricing study undertaken in the USA (further details are provided in the Trucost Natural Capital Valuation Methodology).

Impacts on Human Health

The Trucost Natural Capital Valuation Methodology provides valuation coefficients for the impact of nitrogen and phosphorus emissions to water and was applied to value the impact of fertiliser use on human health. This valuation is based on the estimated excess water treatment cost and the number of DALYs lost due to unsafe drinking water (where water is not treated) per kilogram of nitrogen or phosphorus emitted to water bodies (further details are provided in the Trucost Natural Capital Valuation Methodology). The valuation of water treatment cost impacts is based on a USA study and health effects are valued based on a global value per DALY gained or lost.

2.3.2. Fertiliser Emissions to Air – Ammonia

Volatilisation of ammonia occurs in crops fertilised with chemical nitrogen inputs such as urea, and both reduces the efficiency of nitrogen fertiliser application and imposes negative impacts on human health.

Ammonia emissions from rice fields per hectare were estimated based on the formulas shown in Box 2. The ammonia emission factors applied are not country or crop specific, but include specific emissions factors for different fertiliser types, and were applied to the treatment specific mix of chemical fertilisers or the regional average mix of fertilisers (IFA, n.d.). Organic fertilisers, such as manure, can also produce ammonia emissions to air, however a range of factors, including the manure composition, soil conditions and climate, influence this process (Sommer and Hutchings, 2001). Insufficient data was available to robustly model these processes and therefore ammonia emissions from manure were excluded from this methodology.

The valuation of ammonia emissions from chemical fertiliser was calculated using the formula below:

$V_{NH3} = Q_{NH3} \times VC$

Where;

- V_{NH3} is the monetary value of ammonia emissions to air resulting from chemical fertiliser application ($US, 2015 price year).
- Q_{NH3} is the quantity of ammonia emitted to air (in kilograms per hectare) estimated using the formula in Box 2.
- VC is the Trucost country specific valuation coefficient for ammonia emissions to air ($US, 2015 price year).

Box 2: Estimation of Ammonia Volatilisation from Chemical Fertilisers (Koch and Salou, 2015)

NH_3 Volatilization from Fertilizer

Q_{NH3} = (0.22 x N-U x 0.46) + (N-AB x 0.33) + (N-AS x 0.22) + (N-AP x 0.05) + (N-Other x 0.02) + (B x D/365)

Where:

- N-U is the N content of urea fertiliser applied (kg/ha) **[Study or region specific quantity and global coefficient]**.
- N-AB is the N content of ammonium bicarbonate fertiliser applied (kg/ha) **[Study or region specific quantity and global coefficient]**.
- N-AS is the N content of ammonium sulfate fertiliser applied (kg/ha) **[Study or region specific quantity and global coefficient].**
- N-AP is the N content of ammonium phosphate fertiliser applied (kg/ha) **[Study or region specific quantity and global coefficient]**.
- N-Other is the N content of other fertilisers (including ammonium nitrate, calcium ammonium nitrate, triple superphosphate and potash) applied (kg/ha) **[Study or region specific quantity and global coefficient]**.
- B is the baseline emission of ammonia at 1.5 kg per hectare per annum **[Study or region specific quantity and global coefficient]**.
- D is the duration of the growing period **[Country specific assumption]**.

Note: The calculation of ammonia emissions from urea assumes that 30% is applied during plot preparation, 30% after planting and 40% on the formation of the panicle (Koch and Salou, 2015).

Impacts on Human Health

The Trucost Natural Capital Valuation Methodology (Air, Land and Water Pollutants) provides valuation coefficients for the impact to human health of ammonia emissions to air. This valuation is based on a European study of the human health effects of air pollution and has been adjusted for each study country based on population density. A global value per DALY lost was used to value the health effects of ammonia emissions to air. Further detail on this methodology is provided in the Trucost Natural Capital Valuation Methodology.

2.4. Greenhouse Gas Emissions

Rice cultivation can contribute to changes in the flow of greenhouse gasses to and from the atmosphere. The following section describes the valuation of greenhouse gas emissions from rice cultivation practices.

2.4.1. Fertiliser Emissions to Air – Nitrous Oxide

Nitrous Oxide (N_2O) is produced in agricultural soils and is a potent greenhouse gas with a global warming potential 298 times greater than CO_2 (WRI and WBCSD, 2011).

N_2O emissions per hectare from rice fields are estimated based on the formula described in Box 3. The N_2O emission factors applied are not country or crop specific, but are applied to the study specific quantity of chemical nitrogen fertiliser applied.

Estimated N_2O emissions were converted to CO_2 equivalent on the basis of the relative global warming potentials of N_2O and CO_2 (WRI and WBCSD, 2011).

The valuation of nitrous oxide emissions from fertiliser was calculated using the formula below:

$V_{N2O} = Q_{N2O} \times GWP_{N2O} \times VC$

Where;

- V_{N2O} is the monetary value of nitrous oxide emissions to air resulting from chemical fertiliser application ($US, 2015 price year).
- Q_{N2O} is the quantity of nitrous oxide emitted to air (in kilograms per hectare) estimated using the formula in Box 3.
- GWP_{N2O} is the global warming potential of nitrous oxide relative for carbon dioxide.
- VC is the Trucost global valuation coefficient for greenhouse gas emissions ($US, 2015 price year).

Box 3: Estimation of Nitrous Oxide Volatilisation from Chemical Fertilisers (Koch and Salou, 2015).

N_2O Volatilisation from Fertiliser
$N\text{-}N_2O = (0.0025 \times Nf) + (0.26 \times D/117)$ Where: • Nf is the total N content of chemical fertilizers applied in kg per Hectare **[Practice specific assumption]**. • 0.0025 is the average emission factor from fertilization **[Global assumption]**. • D is the duration of the growing period **[Country specific assumption]**. • 0.26 N kg.ha-1 is the mean base level emission of $N\text{-}N_2O$ during the growing period **[Global assumption]**. *Note: This model does not account for intermittent flooding conditions where nitrification-denitrification is likely to produce increased N_2O emissions (Koch and Salou, 2015).*

Impacts on Climate Change

The Trucost Natural Capital Valuation Methodology (Greenhouse Gases) provides a valuation for the social cost of CO_2 equivalent emissions, which was applied to value the impact of N_2O volatilisation from chemical fertilisers (further details are provided in the Trucost Natural Capital Valuation Methodology).

2.4.2. Methane Emissions from Rice Fields

Methane emissions arise from the anaerobic decomposition of organic material in rice paddies (IPCC, 2006). The rate of methane emission is affected by a range of factors including rice irrigation and land preparation practices, the number of crops per annum, organic amendments to the soil and other country specific factors (ibid). The IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) were applied to estimate methane emissions per hectare. While primary data on all factors influencing methane emissions was not available for all treatments, treatment and country specific data has been applied wherever possible. Estimated methane emissions were converted to CO_2 equivalent on the basis of the relative global warming potentials of CH_4 and CO_2.

Methane emissions per hectare from rice fields are estimated based on the formula described in Box 4.

The valuation of methane emissions from crop management was calculated using the formula below:

$V_{CH4} = Q_{CH4} \times GWP_{CH4} \times VC$

Where;

- V_{CH4} is the monetary value of methane emissions to air resulting from rice cultivation ($US, 2015 price year).
- Q_{CH4} is the quantity of methane emitted to air (in kilograms per hectare) estimated using the formula in Box 4.
- GWP_{CH4} is the global warming potential of methane.
- VC is the Trucost country specific valuation coefficient for greenhouse gas emissions ($US, 2015 price year).

Box 4: Estimation of Methane Emissions from Rice Fields (Koch and Salou, 2015)

Methane Emissions from Rice Field

$EF_i = EF_c \times SF_w \times SF_p \times SF_o \times SF_{s,r}$

Where:

- EF_i is the adjusted daily emission factor per hectare during the growing period **[Global assumption]**.
- EF_c is the baseline emissions factor for continuously flooded fields with no organic amendments (1.30 kg CH_4 per hectare per day) **[Global assumption]**.
- SF_w is the scaling factor for the water regime during the growing period (0.78 for irrigated and 0.27 for rain fed and deep water fields) **[Global assumption]**.
- SF_p is the scaling factor for the pre-season water regime. No data were available on these practices in the input studies so the aggregated adjustment factor was used (1.22) **[Global assumption]**.
- SF_o is the scaling factor for organic amendments (0.645 for rice straw (average adjustment for straw incorporation shortly and long before cultivation) and 0.5 for green manure) **[Global assumption]**.
- $SF_{s,r}$ is the scaling factor for soil and cultivar type. This factor was not used due to a lack of data **[Global assumption]**.

Note on Reported Greenhouse Gas Emissions

In a limited number of cases, primary data on the greenhouse gas emissions arising from the rice field were reported on the original studies identified in the literature review. Where such was identified, this was been reported in conjunction with the estimated CH_4 and N_2O emissions estimated in this analysis (reported as CO_{2e}), however the two estimates are not necessarily directly comparable since the greenhouse gas emissions calculated in this methodology do not include emissions from fuel combustion associated with agricultural machinery nor do they distinguish between different types of irrigation management such as alternate wetting and drying or intermittent flooding.

2.4.3. Greenhouse Gas Emissions from Rice Straw and Husk Burning

The burning of crop residues is not generally considered a net source of CO_2 emissions as the carbon released is assumed to be reabsorbed in the next growing season, however residue burning is considered a source of non-CO_2 greenhouse gases (IPCC, 2006). The quantity of non CO_2 greenhouse gas emissions released per tonne of crop residue burned was estimated using the methodology described for rice straw and husk burning in Section 3.0 and valued based on the greenhouse gas emissions valuation methodology described in Section 2.4.1 and 2.4.2.

The valuation of non-CO_2 emissions from rice straw and residue burning was calculated using the formula below:

$V_{GHG\ Burning} = Q_{non\text{-}CO2\ GHG} \times GWP \times VC$

Where;

- $V_{GHG\ Burning}$ is the monetary value of non-CO_2 greenhouse gas emissions to air resulting from rice straw and husk burning ($US, 2015 price year).
- $Q_{non\text{-}CO2\ GHG}$ is the quantity of non-CO_2 greenhouse gases emitted to air in kilograms per tonne of residue burned.
- GWP is the global warming potential of the non-CO_2 greenhouse gases released.
- VC is the Trucost country specific valuation coefficient for greenhouse gas emissions ($US, 2015 price year).

3. Air Pollutants from Rice Straw and Husk Burning

Rice straw and husk may be burned as a means for rapidly clearing the rice fields in preparation for the next crop or as a fuel source for domestic or industrial use. Rice crop residue burning emits a complex mixture of chemical species to the atmosphere, some of which are valued under the Trucost Natural Capital Valuation Methodology (Air, Land and Water Pollutants). The following rice crop residue combustion products were included in the valuation:

- Acetone
- Toluene
- Isoprene
- Acetonitrile
- Methanol
- Acetaldehyde
- Hydrogen Cyanide
- Phenol
- Furan
- Formaldehyde
- Ammonia
- Nitrogen Oxides
- Particulate Matter
- Sulphur Dioxide

Quantification of the composition of rice straw combustion emissions was based on a study by Akagi et al (2011) which provides emissions factors a range of biomass types, including crop residues which were assumed to be equivalent to rice straw.

Where rice straw was reported to be burned in the source studies, the total quantity of rice straw produced was valued using the valuation coefficients outlined in Table 3 **[Study specific assumption]**. As no data was available on the frequency of rice husk burning as a source of energy, the potential energy value and potential emissions from burning was valued for all studies. The chemical species emitted from rice straw and rice husk burning were assumed to be equivalent.

Table 3. Health, Ecosystem and Total Cost per Tonne of Rice Straw and Husk Burned

Country	Health Cost per Tonne Rice Husk or Straw Burned	Ecosystem Cost per Tonne Rice Husk or Straw Burned	Total Cost per Tonne Rice Husk or Straw Burned
Cambodia	$1,655	$6	$1,661
Costa Rica	$906	$6	$912
Philippines	$1,866	$8	$1,873
Senegal	$215	$2	$217
USA	$853	$5	$859

The valuation of air pollutant emissions from the burning of crop residues (straw and husk) was calculated using the formula below:

$V_{burning} = (Q_n \times VC_n) + (Q_{n+1} \times VC_{n+1}) + (Q_{n+x} \times VC_{n+x})$

Where;

- $V_{burning}$ is the monetary value of air pollutant emissions from the burning of crop residues per tonne ($US, 2015 price year).
- Q is the quantity of the n^{th} pollutant emitted to air (in kilograms per tonne of residue burned).
- VC is the Trucost country specific valuation coefficient (ecosystem and biodiversity) for the n^{th} pollutant emitted to air ($US, 2015 price year).

Impacts on Ecosystems

The ecosystem impact valuations were based on continental scale modelling of the dispersion of emitted chemicals to rural air and a country specific valuation of the complement of ecosystems contained within each country that are affected by each pesticide or herbicide. This method is described in further detail in the Trucost Natural Capital Valuation Methodology.

Impacts on Human Health

The Trucost Natural Capital Valuation Methodology (Air, Land and Water Pollutants) provides valuation coefficients for a range of organic and inorganic pollutants emitted to rural air. These coefficients are based on continent scale modelling of pollutant dispersion for organic pollutants and metals, and European modelling adjusted for population density for inorganic pollutants. Health effects are quantified as the number of DALYs lost per unit of emission and valued based on a global average value per DALY. Further detail on this method is provided in the Trucost Natural Capital Valuation Methodology.

4. Input Costs

This section describes the valuation of selected input costs incurred by rice farmers in the study countries. The range of input costs valued is not exhaustive and was limited by the availability of practice specific data from the literature review.

4.1. Chemical Fertiliser Inputs

No data was available on the cost of chemical fertilisers applied in the studies identified in the literature review. As such, fertiliser inputs **[Study specific]** were valued on the basis of the estimated average price per kilogram of nitrogen, phosphorous or potassium for a representative fertiliser **[Country specific assumption]**. The following representative fertilisers were selected:

- Nitrogen: Urea (CH_4N_2O)
- Phosphorous: Triple Superphosphate / Monocalcium Phosphate ($Ca(H_2PO_4)_2$)
- Potassium: Potash / Potassium Chloride (KCl)

These fertilisers were selected as representative due to their common use in agriculture and as each fertiliser contributes only one of the essential macronutrients for plant growth. The average fertiliser price per tonne in 2014 (indexmundi, 2015a,b,c) was adjusted for the price level ratio of PPP conversion factor (GDP) to market exchange rate in each country to account for differences in purchasing power in the study countries (World Bank, 2015b). Estimated country specific fertiliser prices are shown in Table 4.

Table 4: PPP Adjusted Fertiliser Cost per Kilogram of Nutrient ($US 2015)

Country	Urea	Triple Superphosphate	Potash
Cambodia	$0.20	$0.45	$0.17
Costa Rica	$0.42	$0.96	$0.36
Philippines	$0.25	$0.58	$0.22
Senegal	$0.33	$0.75	$0.28
USA	$0.66	$1.50	$0.56

The valuation of chemical fertiliser inputs is calculated using the formula below:

$$V_F = (Q_N \times VC_N) + (Q_P \times VC_P) + (Q_K \times VC_K)$$

Where;

- V_F is the monetary value chemical fertiliser input expenditure ($US, 2015 price year).
- Q_N, Q_P and Q_K are the quantities of chemical nitrogen, phosphorus and potassium fertilisers applied per hectare respectively.
- VC_N, VC_P and VC_K are the estimated country specific market prices of chemical nitrogen, phosphorus and potassium fertilisers respectively ($US, 2015 price year).

4.2. Organic Fertiliser Inputs

No data was available on the cost of organic fertiliser inputs and thus these costs could not be valued. However in many cases, the organic inputs used were residues or rice cultivation (such as rice straw or rice straw compost) that may be accessed at negligible cost. The benefit associated with the nutrient content of rice straw returned to the soil is valued as described in Section 3.

4.3. Pesticide and Herbicide Inputs

No data was available on the purchase cost of herbicides and pesticides applied in the studies identified in the literature review. As such, average market prices for key pesticide and herbicide products were estimated based on a limited search of advertised market prices on an online business to business marketplace. Alibaba.com is one of the largest online business-to-business trading websites in the world and is targeted at small to medium enterprises. Market prices were averaged across multiple suppliers and converted to prices per kilogram of active ingredient based on the active ingredient concentration and density of each product. Table 5 details the estimated average price per kilogram of active ingredient for each pesticide and herbicide product used in the studies identified in the literature review.

The pesticide and herbicide input costs were calculated using the formula below:

$$V_{PCost} = (Q_n \text{ x } P_n) + (Q_{n+1} \text{ x } P_{n+1})$$

Where;

- V_{PCost} is the estimated cost of pesticide and herbicide inputs ($US, 2015 price year).
- Q_n is the quantity of active ingredient of the n^{th} pesticide or herbicide applied to the rice field (in kilograms per hectare).
- P_n is the estimated average price per kilogram of active ingredient of the n^{th} pesticide or herbicide applied to the rice field.

Table 5. Estimated Average Price per Kilogram of Active Ingredient for Key Herbicide and Pesticide Inputs ($US 2015)

Compound	Average Price per kg Active Ingredient ($US 2015)
2,4-Dichlorophenoxyacetic Acid	$18.94
Bentazone	$48.11
Butaclor	$4.46
Cipermetrin	No Data
Clomazone	$42.67
Propionic acid (proxy for **Cyhalofop-butyl**)*	$55.47
Dalapon	No Data
Dazomet	$18.03
Dimetoate	$5.79
Ethoxysulfuron	$30.96
Fenoxaprop	No Data

Furadan	$27.82
Glyphosate	$12.92
2-Thiohydantoin (proxy for **Imazapic**)*	$20.86
I**midaclorpid**	$16.67
B**ensulfuron methy**	$28.95
Ordram (molinate)	No Data
Oxadiazon	$18.83
Oxifluorfen	$31.76
Pendimethalin	$74.24
Sulfadimethoxine (proxy for **Penoxsulam**)*	$117.27
Pretilachlor	$9.11
Propanil	$37.26
Safaner	No Data
Triazofos	No Data

While this approach is unlikely to precisely represent the market prices experienced by the rice farmers that were the subject of the original studies, it is expected to provide a reasonable approximation of the relative costliness of different forms of chemical pest control.

5. Natural Capital Benefits

This section outlines the methodology applied to quantify and value the natural capital benefits resulting from rice cultivation. This analysis is not exhaustive, as illustrated in Figure 1, and is limited by the availability of relevant biophysical data in the studies identified in the literature review. Key natural capital benefits included in the valuation study include the production of food, organic fertilisers, and biomass fuel.

6.1 Food Production

This section outlines the methodology applied to value the food provisioning services of rice cultivation.

6.1.1 Rice

Rice is the primary food output of rice cultivation. The value of rice production **[Study specific]** as food for the farmer was estimated on the basis of the country specific producer price received per tonne of paddy rice (FAO, 2013a) **[Country specific assumption]**. The most recent available producer price data was for 2012 and was uplifted to 2015 based on the country specific average producer price index for rice from 2006 to 2012 (FAO 2013b). Producer prices applied for each case study country are show in Table .

Table 6. Country Specific Producer Price for Rice ($US per Tonne (2015))

Country	Producer Price ($US 2015 per tonne)
Cambodia	$114
Costa Rica	$647
Philippines	$189
Senegal	$213
United States of America	$465

The valuation of rice production per hectare was calculated using the formula below:

$V_{ProducerI} = Y \times P_{Producer}$

Where;

- $V_{Producer}$ is the monetary value of rice produced per hectare valued at the producer or retail price.
- Y is the rice yield per hectare.
- $P_{Producer}$ is the country specific producer or retail price of rice produced per hectare.

6.1.2 Aquatic Species

Insufficient data was identified in the literature review to enable the valuation of aquatic species production for food in rice fields. However, the final report makes references to other case study countries where such data exists.

6.1 Raw Material Production

This section outlines the methodology applied to quantify and value the natural capital benefits resulting from raw material production as a by-product of rice cultivation. This analysis is not exhaustive, as illustrated in Figure 1, and is limited by the availability of relevant biophysical data in the studies identified in the literature review.

6.2.1 Rice Straw as Organic Fertiliser

An important use of rice straw for farmers in many countries is the application of straw to the rice field as a source of nutrients to improve soil fertility and yield in future years. Where the source study reports that rice straw is returned to the soil, the quantity of straw produced is valued based on the market price of chemical fertiliser that would be required to deliver an equivalent quantity of nitrogen, phosphorous and potassium to that contained within the rice straw. Urea, triple superphosphate and potash were selected as representative nitrogen, phosphorus and potassium fertilisers respectively. These fertilisers were selected as each is commonly used in agriculture and provides only one of the three macronutrients of interest. USA market prices (Indexmundi, 2015a; Indexmundi, 2015b; Indexmundi, 2015c) have been adjusted for price level ratio of PPP conversion factor (GDP) to market exchange rate in each country to account for differences in purchasing power in the study countries (World Bank, 2015b).

Table8 presents the calculated value of nutrients contained within one tonne of rice straw in each of the study countries. These values are based on the assumed nutrient content of rice straw presented in Table 2 **[Global assumption]**.

Table 8. Value of Nutrient Content per Tonne of Rice Straw ($US 2015)

Country	Nitrogen	Phosphorous	Potassium	Total
Cambodia	$1.53	$0.18	$3.45	$5.16
Costa Rica	$3.25	$0.37	$7.34	$10.97
Philippines	$1.98	$0.23	$4.46	$6.67
Senegal	$2.55	$0.29	$5.75	$8.60
USA	$5.11	$0.59	$11.51	$17.20

The valuation of the nutrient content of rice straw applied to the soil was calculated using the formula below:

$V_{Straw\ Nutrient} = Y_{Straw} \times VC_{straw\ Nutrient}$

Where;

- $V_{Straw\ Nutrient}$ is the monetary value of the nutrient content of rice straw rice produced per hectare where straw is applied to the field ($US, 2015 price year).
- Y_{Straw} is the rice straw yield per hectare (in tonnes) where straw is reported to be applied to the soil.
- $VC_{straw\ Nutrient}$ is the country specific estimated value of the nutrient content of rice straw applied to the soil per tonne ($US, 2015 price year).

6.2.2 Rice Straw as Fuel

In theory, rice straw can be used as a fuel input for energy production for domestic use (such as in cooking) or in industrial electricity generation. In practise, difficult and costly logistics make rice straw less suitable for energy production. Accordingly, no data on the market price of rice straw as a fuel for domestic or industrial purposes was identified in the literature. As a hypothetical alternative, the value of rice straw as a fuel for combustion was assessed based on the price of charcoal as an alternative biomass fuel. The average import price for charcoal[1] per kilogram from 2009-2013 (United Nations, 2015) in each study country was adjusted based on the relative energy content of rice straw (15.2 Mj/Kg) and charcoal (29 Mj/Kg) (Elert, 2015). The value calculated for each country (in US dollars) was uplifted to price year 2015 based on the consumer price index in the USA over the relevant period (World Bank, 2015c) and adjusted for PPP.

The value of rice straw per tonne as a substitute for charcoal is given in Table 9.

Table 9. Estimated Value of Rice straw (per Kg) as a Substitute for Charcoal Fuel

Country	Value per Tonne (US$ 2015)
Cambodia	$304
Costa Rica	$278
Philippines	$168
Senegal	$679
USA	$311

The valuation of the energy content of rice straw was calculated using the formula below:

$V_{Straw\ Energy} = Y_{Straw} \times VC_{straw\ Energy}$

Where;

- $V_{Straw\ Energy}$ is the monetary value of the energy content of rice straw produced per hectare where straw or husk is burned for energy production.
- Y_{Straw} is the rice straw yield per hectare (in tonnes) where straw is burned for energy production.
- $VC_{straw\ Energy}$ is the country specific estimated value of the energy content of rice straw per tonne as a charcoal substitute.

6.2.3 Rice Husk as Fuel

Rice husk can also be used as a biomass fuel for domestic or industrial energy production and has been valued in the same was as rice straw (as described in Section 3.2.5.). No primary data on the quantity of rice husk produced or the management of rice husk was available in the source studies identified in the literature review. Rice husk was assumed to be produced at a ratio of 0.2 tonnes per tonne of rice straw (IRRI, n.d.) As the frequency of use of rice husk as an energy source was unknown for all studies, the quantity of rice husk produced in all studies was valued as a potential energy source. The air emissions associated with burning rice husk were also valued for all studies.

[1] Comtrade entry: Wood and articles of wood; wood charcoal // Wood charcoal (including shell or nut charcoal), whether or not agglomerated)

The value of rice husk per tonne as a substitute for charcoal is given in Table 10.

Table 10. Estimated Value of Rice Husk (per Kg) as a Substitute for Charcoal Fuel

Country	Value per Tonne (US$ 2015)
Cambodia	$310
Costa Rica	$283
Philippines	$172
Senegal	$692
USA	$318

The valuation of the nutrient content of rice husk applied to the soil was calculated using the formula below:

$V_{Husk\ Energy} = Y_{Husk} \times VC_{Husk\ Energy}$

Where;

- $V_{Husk\ Energy}$ is the monetary value of the energy content of rice husk produced per hectare where husk is burned for energy production.
- Y_{Husk} is the rice husk yield per hectare (in tonnes) where husk is burned for energy production.
- $VC_{Husk\ Energy}$ is the country specific estimated value of the energy content of rice husk per tonne as a charcoal substitute.

Alternative Approach

FAO has prepared an alternative approach for valuing the energy content of rice husk based on the use of rice husk for electricity production. Assuming that rice husk is produced at a ratio of one tonne of husk per five tonnes of rice grain, and assuming an energy content of rice husk of 500kWh per tonne (GIZ 2014), it is possible to value the energy content of rice husk based on the national average electricity price in each country. In the United States, one ton of husk used for electricity production was estimated to have a value of US$67, in Costa Rica US$95, in Cambodia US$170, in Senegal, US$118 and in the Philippines US$110.

Table 11. Estimated Value of Rice Husk (per Kg) as a Fuel for Electricity Generation

Country	Value per Tonne (US$ 2015)
Cambodia	$170
Costa Rica	$95
Philippines	$110
Senegal	$118
USA	$67

This analysis draws on data from Militar (n.d.), Council for the Development of Cambodia (2015), Energy Information Administration (2015), Costarica.com (2015), CSS West Africa (2014) and GMA. (2015).

8. Country Overview

Table 12 provides an overview of the biophysical data points identified in the literature review for each study country in categories of importance to the valuation process. In many cases a single published study included multiple treatment comparisons (e.g. baseline treatment vs alternative treatment). For example, a total of 23 studies were identified for the Philippines, which included a total of 258 individual treatment comparisons. The valuation methodologies described in this document were applied at the treatment comparison level.

As shown in Table 12, no biophysical data was available for water use in Cambodia, Costa Rica and California, and no pesticide and herbicide data was available for Cambodia.

Table 12. Summary of Biophysical Data Points Identified in the Literature Review by Study Country

Country	Number of Studies	Number of Treatment Comparisons	Number of Treatment Comparisons Reporting Biophysical Data			
			Yield	Water Use	Pesticide and Herbicide Use	Fertiliser Use
Cambodia	20	124	83	Nil	Nil	64
Costa Rica	2	13	13	Nil	1	13
The Philippines	23	258	251	108	24	249
Senegal	14	172	166	62	74	136
California	15	235	177	Nil	15	87

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