# Development of a methodological framework for calculation of carbon footprint of rice production in Vietnam

**Minh Trang Dao***, **Thi Lan Huong Huynh**

*Vietnam Institute of Meteorology, Hydrology and Climate Change*

Received 5 May 2017; accepted 1 August 2017

***Abstract:***

**Currently, there are various standards and guidelines to calculate product carbon footprints in the world such as the Greenhouse Gas (GHG) Protocol of the World Resources Institute/World Business Council for Sustainable Development (WRI/WBCSD), ISO 14067, and PAS 2050. Most of the studies on carbon footprints of rice production adopt the ISO Life Cycle Assessment (LCA) method while very few studies apply PAS 2050 and the Greenhouse Gas Protocol Agricultural Guidance of WRI/WBCSD. However, the above standards and guidelines do not provide a separate methodology for calculating carbon footprints of rice production. From that perspective, this research paper has developed a methodology to calculate the carbon footprints of rice production from the upstream processes, rice production process to post-farm stage. However, several sources of GHG emissions during the life cycle of rice have not been included in this methodological framework due to either the lack of data or complicated calculation methods.**

***Keywords:*** ***product life cycle, rice carbon footprints.***

***Classification number:*** ***6.2***

## Introduction

The term "carbon footprint" is derived as an integral part of the "ecological footprint"[1], whereby "carbon footprint" is understood as the land area that absorbs the amount of $CO_2$ emitted by the humans during their lifetime. However, as climate change has gradually become a global challenge, the concept of "carbon footprint" has developed independently and in a different form from its origin [1] and defined as "the quantity of GHGs expressed in terms of $CO_2$-equivalent ($CO_2$e), emitted into the atmosphere by an individual, organization, process, product, or event from within a specified boundary" [2]. In addition, ISO 14040 defines that carbon footprint is the total amount of $CO_2$ and other GHGs (e.g., methane, nitrous oxide, etc.) emitted during the life cycle of the product.

The scope of the carbon footprint depends on the range of activities to be taken into account, including Tier 1 (on-site emissions), Tier 2 (emissions embodied in purchased energy), and Tier 3 (all other indirect emissions not covered under Tier 2) [3-5]. The choice of direct and indirect emissions is also incompatible with the different studies. In most cases, the inclusion of all indirect emissions is very complex; therefore, many studies on carbon footprint calculate only direct emissions or indirect emissions in Tier 2 [4, 6, 7]. However, indirect emissions can account for most of the carbon footprints of many activities.

Carbon footprint calculations can be carried out based on a product-based approach or an activity-based approach, i.e. GHG emissions from activities of individuals, groups or organizations. The carbon footprints of activities are the annual GHG emission inventories of individuals, groups, organizations, companies, and governments. One of the guidelines for calculating the carbon footprints of activities is IPCC Guidelines for National Greenhouse Gas Inventories [8]. The product carbon footprint (PCF) refers to the life cycle assessment of the whole/part of the product or service

[1]Ecological footprint refers to the biologically productive land and sea area required to sustain a given human population expressed as global hectares.

*Corresponding author: Email: daominhtrang@gmail.com.

life cycle. Since 2009, government agencies and international organizations have made significant strides in developing standards and guidelines for calculating PCF [9]. At present, three PCF calculation guidelines are universally accepted, including PAS 2050 of the British Standards Institute (BSI), the GHG Protocol of the WRI/WBCSD, and ISO 14067. All the three standards are based on the LCA method specified in ISO 14040 and ISO 14044.

## Methodological framework for calculating carbon footprint

The methodology of this study is based on the reference to the GHG Protocol Agricultural Guidance of WRI/WBCSD, the IPCC Guidelines for National Greenhouse Gas Inventories in 2006 (GL 2006), the Good Practice Guidance for Land Use, Land Use Change and Forestry (GPG LULUCF 2003), the Good Practice Guidance and Uncertainty Management in National GHG Inventories (GPG 2000), and other relevant studies. The calculation process of carbon footprints of rice production consists of five steps:

**Step 1:** Select the GHGs under the regulation of the Kyoto Protocol.

**Step 2:** Determine the scope of calculation: GHG emissions from upstream processes (production of electricity, fertilizer, lime and pesticides); rice production (rice cultivation, land use change, operation of agricultural machinery, groundwater extraction, fertilizer and lime use), and post-production of rice (straw burning on the farms).

**Step 3**: Collect activity data.

The activity data can usually be obtained from existing data such as bills, electricity meters, production records, and land registration records, etc. In general, data on energy purchase and production can commonly be collected with high quality. On the contrary, it is difficult to collect reliable data on land management and land use change [3].

**Step 4:** Calculate carbon footprint.

***a) Calculate GHG emissions/removals***

Specific calculation formulas will be presented in more detail later in the section “Calculation of GHG emissions and removals in the life cycle of rice”.

***b) Calculate carbon footprint***

Global warming potential (GWP) of all tiers is calculated individually using the conversion factor of IPCC (2007). The formula for calculating GWP of $tier_i$ (i = 1, 2 or 3) is as follows:

$GWP(tier_i)$ = emission/removal of $CH_4$ x 25 + emission/removal of $N_2O$ x 298 + emission/removal of $CO_2$

where:

GWP is in kg $CO_2$e/ha.

The carbon footprint is calculated by summing the GWP of all tiers and its unit can be presented as spatial or yield-scaled carbon footprints, which are calculated as follows:

$$CF_s = \sum_{i=1}^{3}[GWP(tier_i)]$$

$$CF_y = \frac{CF_s}{Grain\ yield}$$

where:

$CF_s$: Spatial carbon footprint (kg $CO_2$e/ha)

$CF_y$: Yield-scaled carbon footprint (kg $CO_2$e/yield).

This study will use carbon footprint by yield, i.e. kg$CO_2$e/kg rice.

**Step 5:** Analysis of uncertainty (optional).

Two reasons for the uncertainty of the calculation results are the uncertainty of the model and of the data. The results of GHG emission calculation cannot avoid the uncertainty.

## Calculation of GHG emissions and removals in the life cycle of rice

***GHG emissions from the production of inputs for rice cultivation***

*$CO_2$ emissions from electricity generation for rice cultivation:*

Emissions from the burning of fossil fuels such as diesel and natural gas during the operation of agricultural machinery are direct emissions. Meanwhile, emissions from the generation of electricity used in the operation of agricultural machinery are indirect due to the burning of fossil fuels during electricity production. GHG emissions from electricity generation for rice cultivation are calculated according to the formula given below:

$$\text{GHG emissions} = \text{electricity consumption} * EF_{grid} \quad (1)$$

where:

GHG emissions = GHG emissions from electricity generation (t$CO_2$e)

Electricity consumption = Amount of consumed electricity for the operation of agricultural machinery (MWh)

$EF_{grid}$ = Emission Factor = 0.6612 t$CO_2$/MWh (According to Decision No. 605/KTTVBDKH-GSPT of the Department of Climate Change dated 19 May 2016 on emission factor (EF) of Viet Nam’s electrical grid, 2014).

*GHG emissions from the production of fertilizers and lime:*

GHG emissions from fertilizer production depend on different production technologies and energy sources [10, 11]. This analysis includes emissions from three main nutrients (N, P, K) and agricultural lime ($CaCO_3$). $CO_2$ emissions from the production of the above substances are attributable to the use of energy during production and transportation. In order to calculate indirect emissions from the production and transportation of fertilizers and lime, the mean emission factor is derived from [12] and multiplied by the amount of fertilizer application rate using the following formula:

$$\text{Emissions} = \text{application rate} * EF_{\text{fertilizer/lime}} \quad (2)$$

where:

Application rate = amount of fertilizer/lime application rate per hectare (kg/ha)

$EF_{fertilizer/lime}$ = emission factor for the production of fertilizer and lime (kg $CO_2$e/kg fertilizer/lime). Kool, et al. (2012) has provided $EF_{fertilizer/lime}$ for N, P, K and lime for global, Western Europe, Russia and Central Europe, North America, China, India and the other countries.

*GHG emissions from the production of pesticides:*

Energy consumption in pesticide production depends on the composition and the production process employed. The emission factor of 0.069 kg $CO_2$e/MJ from [13, 14] can be used to calculate emissions from pesticide production. If all electricity used to produce pesticides is generated from nuclear or hydropower, which emit less carbon, the above factor will be 0.049. Where the data on the application rate of pesticide are available, the $CO_2$e emissions are calculated using the following formula:

$$\text{Emissions} = \text{Input energy} * \text{Application rate} * \text{EF pesticides} \quad (3)$$

where:

Input energy = energy used to produce 1 kg of pesticide (MJ/kg)

Application rate = the application rate of common pesticides (kg/ha)

$EF_{pesticides}$ = emission factor of energy for the production of pesticides (kg$CO_2$e/MJ).

***Greenhouse gas emissions from rice cultivation***

*Methane emissions from rice cultivation:*

Based on IPCC (2006), $CH_4$ emissions are calculated using formula (4), where $CH_4$ emissions are estimated by multiplying daily emission factors by means of rice cultivation period and annual harvest area.

$$CH_{4\,rice} = \sum_{i,j,k}(EF_{i,j,k} * t_{i,j,k} * A_{i,j,k} * 10^{-6}) \quad (4)$$

where:

$CH_{4\,rice}$ = Annual methane emissions from rice cultivation (Gg $CH_4$ per year)

$EF_{ijk}$ = Daily emission factor under i, j, and k conditions (kg $CH_4/m^2$/day)

$t_{ijk}$ = Cultivation period of rice under i, j, and k conditions (days)

$A_{ijk}$ = Annual harvested area under i, j, and k conditions (ha/year)

i, j, and k = different ecosystems, water regimes, type and amount of organic amendments, and other conditions under which $CH_4$ emissions from rice may vary.

Emissions from different regions are adjusted by multiplying a baseline default emission factor. According to GPG 2000, the daily emission factor can be calculated using the following formula:

$$EF_i = EF_c * SF_w * SF_{pj} * SF_o * SF_{s,r} \quad (5)$$

where:

$EF_i$ = Adjusted daily emission factor for a particular harvested area

$EF_c$ = Baseline emission factor for continuously flooded fields without organic amendments

$SF_w$ = Scaling factor to account for the differences in water regime during the cultivation period (continuously flooded = 1, error range = 0.79-1.26)

$SF_{pj}$ = Scaling factor to account for the differences in water regime in the pre-season before the cultivation period (less than 30 days = 1.9, error range = 1.65 and 2.18 source)

$SF_o$ = Scaling factor that accounts for differences in both type and amount of organic amendment applied

$SF_{s,r}$ = Scaling factor for soil type, rice cultivar, etc.

Emissions increase as the amount of organic material increases. Formula (6) and the default conversion factor for farm yard manure present an approach to vary the scaling factor according to the amount of manure used on the farm (IPCC, 2007) [15].

$$SF_o = (1 + \sum_i ROA_i * CFOA_i)^{0.59} \quad (6)$$

where:

$SF_o$ = Scaling factor for both type and amount of organic amendment applied

$ROA_i$ = Rate of application of organic amendment *i*, in dry weight of straw and fresh weight for others (tonnes/ha)

$CFOA_i$ = Conversion factor for organic amendment *i*. According to IPCC (2006) [16], the default conversion factor for farmyard manure is 0.14 with an error range of 0.07-0.2.

*Carbon stock change in the living biomass due to land use change:*

GPG LULUCF classifies the national land into six categories, i.e. Forest Land, Cropland, Grassland, Wetlands, Settlements, and Other land and subdivides each of them into two subcategories on the basis of whether or not land conversion has been occurred. The GHG emissions and removals in LULUCF include the carbon stock changes in living biomass (aboveground/belowground), litter, and soil. According to the assumption of GPG LULUCF 2003, the carbon stock in the biomass of all land uses is zero after conversion. Formula (7) is used to calculate the biomass stock change associated with land use change, except for the conversion from Forest Land to Cropland:

$$\Delta C = A\ (conversion\ )*[(C_{Before} - C_{After}\ )+\Delta C_{Growth}] \quad (7)$$

where:

$\Delta C$: Annual change in carbon stocks in living biomass in land converted from "before" to "after" (tonnes C/yr)

$A_{Conversion}$: Annual area of land converted from "before" to "after" (ha/yr)

$C_{After}$: Carbon stocks in biomass immediately after conversion (tonnes C/ha)

$C_{Before}$: Carbon stocks in biomass immediately before conversion (tonnes C/ha)

$\Delta C_{Growth}$: Changes in carbon stocks from one year growth of land "after" (tonnes C/ha).

For the conversion from Forestland to Cropland, the decrease in carbon in living biomass will be calculated according to the following formula:

$$C_{loss}=L_{wood\text{-}removals}+L_{fuelwood}+L_{other\ losses} \quad (8)$$

$$L_{wood\text{-}removals}=H*BCEF_r*(1+R)*CF \quad [8a]$$

$$L_{fuelwood}=FG*D*CF \quad [8b]$$

$$L_{other\ losses}=A_{disturbance}*B_W*(1-f_{BL})*CF \quad [8c]$$

where:

$C_{Loss}$: Annual decrease in carbon stocks due to biomass loss, tonnes C/yr

CF: Carbon fraction of dry matter (tonnes C/tonne d.m)

R: Ratio of below ground biomass to above ground biomass (root-to-shoot ratio), dimensionless

$BCEF_i$ (= $D*BEF_i$): Biomass conversion and expansion factor for expansion of annual net increment in volume (including bark) to aboveground biomass increment (tonnes d.m/m$^3$), equivalent to basic wood density multiplied by biomass expansion factor

$L_{wood\text{-}removals}$: Annual carbon loss due to biomass removals (tonnes C/yr)

$L_{fuelwood}$: Annual carbon loss due to fuelwood gathering (tonnes C/yr)

$L_{other\ losses}$: Annual other losses of carbon (tonnes C/yr)

H: Annual wood removals, roundwood (m$^3$/yr)

FG: Annual volume of fuelwood gathering (m$^3$/yr)

$BCEF_r$ (= $D*BEF_r$): Biomass conversion and expansion factor for conversion of removals in merchantable volume to biomass removals (including bark) (tonnes d.m/m$^3$), equivalent to basic wood density multiplied by biomass expansion factor

D: Wood density (tonnes d.m/m$^3$)

$A_{disturbance}$: Areas affected by disturbances (ha)

$B_W$: Average annual above-ground biomass of land areas affected by disturbance (tonnes d.m/ha/yr)

$F_{BL}$: Fraction of biomass lost in disturbance.

Formula (9) is used to calculate the emissions from biomass burning:

$$L_{fire}=A*B*C*D*10^{-6} \quad (9)$$

where:

$L_{fire}$: Quantity of GHG released due to fire (tonnes of GHG)

A: Area burned (ha)

B: Mass of "available" fuel (kg d.m/ha)

C: Combustion efficiency (or fraction of the biomass combusted), dimensionless

D: Emission factor (g/kg d.m).

*Greenhouse gas emissions from on-farm machinery use for field operation:*

In farming, three types of fuel are commonly used, including diesel, natural gas and electricity. Diesel is used for rice production and machine operation in the field. Natural gas and electricity are used more often for farm operations such as underground water intake, machine maintenance, and drying. According to IPCC (2006), GHG emissions from diesel combustion for the operation of agricultural machines are calculated based on the following formula:

$$GHG\ emissions = amount\ of\ used\ fuel * EF_{fuel} \quad (10)$$

According to Table 2.5, p.2.2 of GL 2006, the default emission factor for stationary emissions of diesel in agriculture is 74528.8 kg $CO_2$t/TJ.

*Greenhouse gas emissions from the extraction of groundwater for irrigation:*

GHG emissions from irrigation are calculated based on the energy required for extraction (pumping) and water application. Irrigation is the primary consumer of energy on farms especially when pumping is required. Therefore, any changes in irrigation methods can lead to a change in on-farm energy consumption. The direct energy inputs are mainly used for the operation of agricultural machinery and pumps, while indirect energy inputs refer to energy that is used to produce equipment and other products and services used on-farm. When groundwater is used, a lot of energy is required for pumping water.

$CO_2$ emissions from irrigation are calculated based on the energy needed for extraction and application of water. The calculation of $CO_2$ emissions from water absorption is based on the assumption that the energy required to extract water from a surface source is negligible and only the amount of energy to extract groundwater is calculated. In addition, the study assumes that water source is in close proximity to the field and the water is conveyed to the farm by gravity.

The energy used for water extraction is the energy required to lift 1 $m^3$ of water (1000 kg $m^3$) up to 1 m at 100% efficiency of 0.0027 kWh [17]. GHG emissions are calculated by multiplying energy consumption by emission factor.

$$\text{Energy (kWh)} = \frac{9.8ms^{-2} * Lift\ (m) * Mass\ (kg)}{3.6 * 10^{6} * Efficiency\ (\%)} \quad (11)$$

where:

Energy = Energy used to extract water from shallow and deep wells

Lift = Average depth value (m)

Efficiency = Efficiency ranges from 11-30% for electric pumps and 40-67% for diesel engines

Mass = Amount of groundwater used for irrigation ($m^3$/year).

Then the $CO_2$ emissions from the use of diesel pumps will be calculated by taking the amount of energy consumed and the emission factor of the diesel engine. According to Table 2.5, p.2.2 of IPCC (2006), the default emission factor for stationary emissions of diesel burning in agriculture is 74528.8 kg $CO_2$t/TJ.

For electric pumps, $CO_2$ emissions are calculated by multiplying the amount of energy consumed by the emission factor of Vietnam's electrical grid in 2014 (0.6612 $tCO_2$/MWh).

*Greenhouse gas emissions from fertilizer application:*

GHG emissions from the application of N, P and K fertilizers are calculated by multiplying the amount of applied fertilizer by the emission factor of fertilizer application by type derived from (12).

$$\text{Emissions} = \text{Application rate} * EF_{\text{fertilizer application}} \quad (12)$$

where:

Emissions = Emission level ($CO_2$e)

Application rate = Amount of applied fertilizer (kg)

EF = Emission factor of fertilizer application ($CO_2$e/kg fertilizer).

*Greenhouse gas emissions from lime application to soil:*

Lime is commonly used to manage soil and grasslands to reduce soil acidity. Lime is commonly applied as crushed limestone ($CaCO_3$) or crushed dolomite ($CaMg(CO_3)_2$). Adding lime to soil leads to $CO_2$ emissions as the carbonate limes dissolve and release bicarbonate ($2HCO_3$), which will decompose into $CO_2$ and water. The $CO_2$ emissions from the dissolution of carbonate rock do not include the emissions from fossil fuel used to crush, transport, and spread the crushed rock on the field. The direct emissions of lime application to soil is calculated by multiplying the amount of lime application (kg) by the emission factor of crushed limestone or dolomite. According to GPG LULUCF (2003), the carbon emission factor of the crushed limestone is 0.12 (tC/ton) and that of crushed dolomite is 0.122 (tC/ton). Carbon emissions are converted to $CO_2$ emissions by using the following formula: $CO_2e=44/12*C$.

*GHG emissions from on-farm straw burning:*

Straw is the main by-product of rice production. In recent years, on-farm straw burning has been increasing and negatively affecting the environment, human health, and contributing to global climate change. This study assumes that GHG emissions in post-production of rice are mainly from the burning of straw on farm. The calculation of GHG emissions from straw burning is based on the methodology of similar studies such as Nam, et al. [18], which includes the following steps:

Step 1: Determine the straw-to-grain ratio

Straw-to-grain ratio is calculated according to the following formula:

$$R = \frac{W_r}{W_h} \quad (13)$$

where:

R: Straw-to-grain ratio

$W_r$: Dry weight of straw (kg)

$W_h$: Weight of rice (kg).

According to Le, et al. [19], the rate of on-farm straw burning in Thai Binh province is respectively 51% and 78.5% during the winter-spring and autumn-winter season. This is because in the winter-spring season, farmers often cut the tops of the rice, and due to high temperature most of the straw is plowed into the soil, thus significantly reducing the burning rate. In the autumn-winter season, farmers often cut the rice from the roots, then dry or burn, and hence the rate of straw burning is higher.

Step 2: Calculate the amount of straw generated after harvest

The amount of straw generated per crop is calculated by the following formula:

$$\text{Amount of straw generated} = \text{Rice yield} * \text{Straw/grain ratio} \quad (14)$$

Step 3: Estimate the quantity of burned straw on farm

The quantity of burned straw on the farm is calculated according to the following formula:

$$Q_{st} = Q_p \times R \times k \quad (15)$$

where:

$Q_{st}$: Quantity of burned straws on farm (tonnes)

Qp: Quantity of rice yield (tonnes)

R: Straw-to-grain ratio

k: Ratio of straw burned on farm to total straw quantity.

Step 4: Calculate GHG emissions from burned straw

GHG emissions from straw burning are calculated by the following formula:

$$E_i = Q_{st} \times EF_i \times F_{co} \quad (16)$$

where:

$E_i$: Emissions of i into the environment due to burning straw on farm (tonnes)

$EF_i$: Emission factor of *i* emissions from on-farm straw burning (g/kg) (based on Gadde, et al. (2009) with $E_{CO2}$ = 1464; $E_{CO}$ = 34.7; $E_{NOx}$ = 3.1)

$F_{CO}$: Rate of conversion to gas when burning straw. $F_{CO}$ = 0.8 [20].

## Conclusions

In conclusion, PAS 2050, the GHG Protocol of WRI/WBCSD, and ISO 14067 are commonly accepted standards and guidelines for calculating carbon footprints which are based on the process approach and LCA as regulated in ISO 14040/44. Most of the studies in the world have used the LCA method to calculate carbon footprints during the rice life cycle. Several studies have used both LCA method of ISO and GHG inventory guidelines. Very few studies used PAS 2050, the GHG Protocol Agricultural Guidance of WRI/WBCSD and ISO 14067. The purpose of the LCA is to assess the environmental impact of the entire life cycle of products/services; therefore, future studies should use standards, guidelines for calculating product carbon footprint. In addition, the above-mentioned guidelines for PCF calculation have yet to develop a separate methodology for calculating rice carbon footprints. Therefore, this study has developed a methodological framework for calculating rice carbon footprints, from upstream processes, rice production to post-farm stage. However, there remain sources of GHG emission in the life cycle of rice that have not been included in this methodological framework due to either the lack of input data or complicated calculation methods. They are GHG emissions from seed production and transportation of materials to the field, carbon stock changes in litter and soil due to land use changes, GHG emissions during rice distribution and consumption, HFC and PFC emissions from air conditioners and refrigerators, and other emissions apart from burning straw during the disposal process. These issues need to be further researched to refine the methodology in the future.

## REFERENCES


[1] A.J. East (2008), "What is a carbon footprint? An overview of definitions and methodologies", *Vegetable industry carbon footprint scoping study - discussion papers and workshop*, Horticulture Australia Limited, Sydney.

[2] D. Pandey, M. Agrawal, J.S. Pandey (2011), "Carbon footprints: Current methods of estimation", *Environmental Monitoring and Assessment*, **178**, pp.135-160.

[3] WRI/WBCSD (2013), *Greenhouse gas protocol agricultural guidance: Interpreting the corporate accounting and Reporting standard for the agricultural sector*, Geneva.

[4] Carbon Trust (2007), *Carbon footprint measurement methodology*, Version 1.1, The Carbon Trust, London, UK.

[5] BSI (2008), *PAS 2050:2008: Specification for the assessment of the life cycle greenhouse gas emissions of goods and services*, United Kingdom.

[6] T. Wiedmann, J.A. Minx (2007), *Definition of carbon footprint*, ISA-Research and Consulting, Durham.

[7] H.C. Matthews, C.T. Hendrickson, C.L. Weber (2008), "The importance of carbon footprint estimation boundaries", *Environmental Science and Technology*, **42(16)**, pp.5839-5842.

[8] M.J. Franchetti and D. Apul (2013), *Carbon footprint analysis: Concepts, methods, implementation, and case studies*, Taylor & Francis Group, Boca Raton. London - NewYork.

[9] Cong Khanh Doan, Thi Thanh Huyen Truong, Huy Hoan Tran, Thi Kim Tuyen Vo, Van Thang Tran, Hong Thom Nguyen, Trung Thanh Ho, Ngoc Thinh Tran and Huu Lam Son Nguyen (2014), *Assessment of the current status and development trends of the market for low-carbon commodities in Vietnam and on the world and propose solutions to promote*, Summary report 04.14/CC, Ministry of Industry and Trade.

[10] F. Cherubini (2010), "GHG balances of bioenergy systems - Overview of key steps in the production chain and methodological concerns", *Renewable Energy*, **35**, pp.1565-1573.

[11] S. Wood and A. Cowie (2004), *A review of greenhouse gas emission factors for fertiliser production*, Research and Development Division, State Forest of New South Wales.

[12] A. Kool, M. Marinussen, and H. Blonk (2012), *LCI data for the calculation tool Feedprint for greenhouse gas emissions of feed production and utilization: GHG emissions of N, P, K fertilizer production*, Blonk Consultants, Netherlands.

[13] E. Audsley, K. Stacey, D.J. Parsons, A.G. Williams (2009), *Estimation of the greenhouse gas emissions from agricultural pesticide manufacture and use*, Cranfield University.

[14] A.G. Williams, E. Audsley, D.L. Sandars (2006), *Final report to Defra on project ISO 205*.

[15] IPCC (2003), *Good Practice Guidance for Land Use, Land-Use Change and Forestry*, IGES, Japan.

[16] IPCC (2006), *IPCC Guidelines for National Greenhouse Gas Inventories*, IGES, Japan.

[17] S. Rothausen and D. Conway (2011), "Greenhouse gas emissions from energy use in the water sector", *Nature Climate Change*, **1**, pp.210-219.

[18] Sy Nam Tran, Thi Huynh Nhu Nguyen, Huu Chiem Nguyen, Vo Chau Ngan Nguyen, Hoang Viet Le, Kjeld Ingvorsen (2014), "Estimation of straw yield and treatment measures in some provinces in the Mekong River Delta", *Journal of Science of Can Tho University*, **32,** pp.87-93.

[19] Le Hoang, Thi Thu Hanh Nguyen, Thuy Linh Le (2013), "Estimation of greenhouse gas emissions from straw burning on farms in Thai Binh province", *Journal of Science*, Vietnam National University, Hanoi, **29(2)**, pp.26-33.

[20] B. Gadde, S. Bonnet, C. Menke, S. Garivait (2009), "Air pollutant emissions from rice straw open field burning in India, Thailand and the Phillippines", *Journal of Environmental Pollution*, **157(5)**, pp.1554-1558.