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A Study on Greenhouse Gas Emissions of Paddy Cultivation Mechanization in Mekong Delta, Viet Nam

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***Abstract*—Viet Nam is still an agricultural country because half the people work in the agricultural sector. The total rice export passed more than seven billion US dollars in 2021, taking over nearly 17% of the one agricultural production export of the country. Mekong Delta is considered the granary of Vietnam. With a total paddy area of 4.07 million ha, the annual rice production was 24.3 million tons, accounting for half of Viet Nam rice production. The rice production in the Mekong Delta is done mostly by machines that use mostly diesel oil and gasoline. The Mekong Delta's power level of rice farming is around 3.17 HP/ha. The application of machines in rice farming has many advantages. However, it also contributes to increased greenhouse gas emissions from burning fuel (direct emission) and manufacturing (indirect emission) of our earth's machines that cause rising temperatures, unpredicted weather events, and some other impacts referred to generically as 'global warming'. This paper studies the impacts of using machines in paddy production mechanization in Mekong Delta on the greenhouse gas emission. The results indicate that the direct CO2 eq. emission in rice farming operations is 0.22 ton/ha per cropping season, and the indirect CO2 eq. emission is 0.02 tons/ha. With the paddy area of 4.07 million ha in the Mekong Delta, total CO2 eq. emission from mechanization in rice farming corresponds to 733,000 tons/year.**

***Keywords*— Agricultural mechanization; fossil fuel; greenhouse gas emission; Mekong delta.**

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I. INTRODUCTION

The exhaust of greenhouse gas (GHG) will create the phenomenon called the 'greenhouse effect' that strongly affects our globe on both sides. The first one is this phenomenon is necessary to keep the temperature of our planet in an acceptable range for life. Oppositely, excessive GHG emissions cause harmful influences on our earth [1]-[5]. The concentration of GHG in the atmosphere has increased significantly since the start of the Industrial Revolution, with the main contribution of fossil fuels used in many industrial fields [6]-[10]. This growth is due to human activity [11]-[13]. The increasing GHG leads to rising temperatures in our sphere, weather events, and some other impacts referred to generically as 'global warming' [14]-[18]. The global GHG emissions come from different sources; agricultural production is not small, with around 13 %, which equals 5.79 billion tons, as shown in Fig.1 [19]. Viet Nam is still a developing country, with nearly half working in the agricultural sector. The total exported value by agriculture products takeover of nearly 25% of the country in which rice export will pass to more than seven billion US dollars in 2021 [20].

Mekong Delta, with a total cultivated area of 4.07 million ha and 24.3 million tons of rice productivity, is considered a granary of Vietnam, where it accounts for more than 90% of rice export and 50% of rice production of Viet Nam annually [20]. The average rice yield of the two crops in Mekong Delta is about 5.5 – 7.0 tons/ha. The mechanization ratio of paddy products in this region is standing at the highest level of Viet Nam. Most of the stages of paddy production, including land preparation, levelling, sowing/seeding, caring, spraying, harvesting, and transporting in the Mekong Delta region, are done by machines in which the main power is diesel engines [21]. Land preparation and harvesting are two stages taking a lot of power, and they are done by machine with 100%. Therefore, the machines equipped for paddy production are at this region's highest agricultural mechanization ratio. The potential power source equipped for agriculture production is 2.4 HP/ha in Vietnam [22].

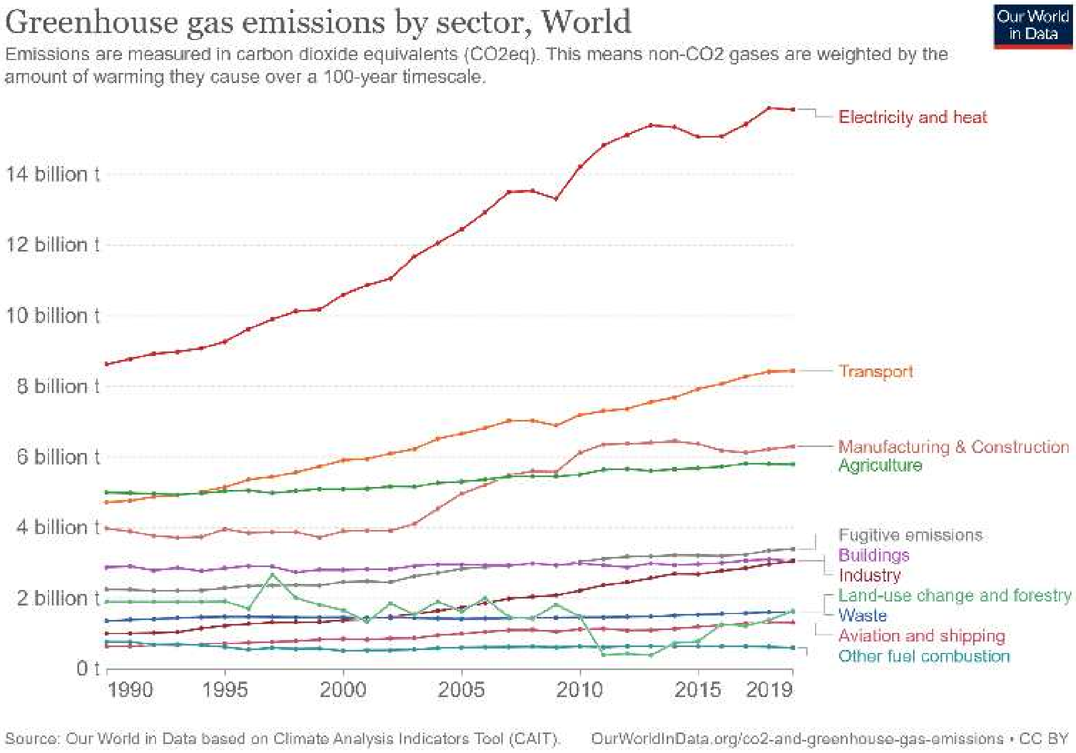

Fig. 1 The GHG in the world by sector [19]

However, it is not equal to different provinces. For example, Vinh Long is one of the provinces in the Mekong Delta with a high-power source equipped, about 5 HP/ha, which is 3.2 HP/ha for rice production [23]. Many machines used for paddy production in the area that takes over 50% of the one in Viet Nam should exhaust many kinds of gases, affecting an environment that might threaten sustainability production in Viet Nam. In the exhaust gas of dual fuel combustion, CO_2, CH_4, and N_2O are the three primary greenhouse gas (GHG) components. The global warming potential of CH_4 is 21 times that of CO_2. Emitted CO is transformed in the atmosphere to CO_2 after some time. A global warming potential factor is calculated for CO with a ratio of 1.57 kg CO_2-eq per kg of CO [24].

A regional analysis of paddy production in the Mekong Delta is helpful because such studies have not been done, but because it might provide perspective on the GHG emissions in the agriculture production sector around the world. This study aims to analyze primary fossil energy inputs and GHG emissions for paddy production to find some approaches to reducing the negative effects of agriculture's mechanization process. With the rapid development of mechanization in paddy production in the Mekong Delta, this paper will address the impact of paddy mechanization in this region on rising atmospheric levels-of CO_2 and other greenhouse gases (GHG) emissions besides the contribution to the reduction in production cost, increase in rice yield, and saving input materials.

II. Materials and Methods

A. The Scope, Limited Boundary, and Study Units

This study aims to estimate the variation in primary fossil energy inputs and GHG emissions associated with the mechanization process of paddy production in Mekong Delta, Viet Nam. The Level of Mechanization (LOM) and the mechanization index (MIE) of the paddy production in all Mekong Delta provinces have been conducted for this assessment. These regions in Mekong Delta are shown in Fig.2, in which three provinces are chosen for study based on differences in the level of each stage of the mechanization process. The scope of the analysis included agricultural production and delivery of harvested cane to a sugar mill or biorefinery. Some equipment, such as farm machinery and vehicles, are assumed to have a small-scale contribution to GHG emissions.

Fig. 2 Thirteen provinces in Mekong Delta were used in the study.

Fossil fuel and GHG emissions are the impact categories in this study. Fuel, electricity, and agricultural machine inputs' production, transportation, and manufacturing are applied to accessing the impacts. Mechanization of agricultural production inputs is estimated on an area basis and adjusted based on paddy yield under each production situation. Fossil energy use and GHG emissions are computed based on a functional unit of 1 ha of paddy cultivation.

B. Level of Mechanization in Rice Farming

In this study, the mechanization index (MI_E) and Level of Mechanization (LOM) are the two criteria for the evaluation of mechanization application in different operations in rice farming. Mechanization index (MI_E) is expressed by the percentage of machine work E_M to the sum of manual E_H, animal E_A, and machine work E_M, as shown in the following formula [25]:

$$MI_E = \frac{E_M}{E_T} = \frac{E_M}{E_H + E_A + E_M} \quad (1)$$

Where MI_E is the mechanization index (%), E_H is the work by humans (kWh/ha), E_A is the work by animals (kWh/ha), E_M is the sum of all mechanical, operational works of the machine (kWh/ha). The power is 0.10 HP for humans, 0.67 HP for carabao, 0.45 HP for cattle, and 1.0 HP for horses. Animals have not been used for draft purposes in farm operations in Mekong Delta. In addition, the efficiency factor is 80% for motors and engines, 85% for tractors, and 80% for other powered machines [26].

The Level of Mechanization (LOM) is determined based on the total available electrical and mechanical power and the total farmland area cultivated [25-26], as the following formula:

$$\mathrm{LOM} = \frac{\mathrm{P}}{\mathrm{A}} \quad (2)$$

Where: LOM is the Level of Mechanization (HP/ha), P is the total available electrical and mechanical power (HP), and A is the total farmland area cultivated (ha). The total available electrical and mechanical power was determined based on the number of machines and their power with the correction factor of 0.75 for electrical power.

C. Fuel combustion & GHG emission

Most machines applied in rice farming use diesel oil and gasoline as fuel, such as tractors, rice transplanters, combine harvesters, grain conveyor machines, self-propelled straw balers, etc. Besides, other machines, like water pumps for irrigation and drones for pesticide spraying, use electric energy for operation.

The fuel consumption in different operations was measured from several machines operating in rice fields in Mekong Delta. Those machines include a rotary tiller (1.8-m width) coupled to a 49-HP tractor (Fig.3); combine harvester DC70 (Fig.4); stubble chopper coupled to 28-HP tractor; 26-HP tractor hauled straw baler and self-propelled straw baler coupled to 60-HP engine; self-propelled rubber track vehicle with 50-HP engine used for in-field transporting of grain. It was computed as the following formula:

$$\mathrm{F} = \frac{\mathrm{F_e}}{\mathrm{F_c}} \quad (3)$$

Where: F is the fuel consumption (L/ha), F_e is the fuel consumption of traction engines (L/h), F_c is the field capacity (ha/h), both were derived from in-field measurements.

Fig. 3 Tractor hauled rotary tiller.

For diesel oil, the constituent of Carbon accounts for 85.9% by weight, and the percentage of Sulphur is from 0.05 to 0.5%. Thus, burning fuel oil produces Carbon dioxide (CO_2) and Sulphur dioxide (SO_2), which causes acid rain for climate change. With 55% of excess air, burning 1 kg of diesel fuel produces 3.15 kg of CO_2 and 0.01 kg of SO_2 [27-28]. For natural gas, the constituent is mostly methane (CH_4). Based on the principle of combustion of methane, each kg of methane burned produces 2.75 kg of CO_2 [27].

In addition, GHG emission was also determined through energy consumption. The most energy coefficients for diesel and gasoline were taken as 45 and 42 MJ/liter, and the base CO_2 emissions factors associated with diesel and gasoline were considered 0.07 and 0.06, respectively. Meanwhile, the average electricity emission factor was 0.03 kg CO_2/MJ [29].

Fig. 4 Combine harvester operating in the paddy field.

A global warming potential factor is calculated for CO with a ratio of 1.57 kg CO_2-eq per kg CO [30]. Total CO_2 eq. emission from burning straw was computed as the following formula:

$$E_{CO2\,eq.} = E_{CO2} + a * E_{CH4} + b * E_{N2O} \quad (4)$$

Where: $E_{CO2\,eq.}$ is the total CO_2 eq. emission (ton/ha), E_{CO2} is the CO_2 emission (ton/ha), (= k * RS_c), RS_c is the rice straw yield (ton/ha), k is the emission factor (k = 1.2), kg of CO_2 per kg of rice straw, a is the global warming potential factor of CH_4 (= 21), b is the global warming potential factor of N_2O

(= 300), E_{CH4} is the CH_4 emission (ton/ha), E_{N2O} is the N_2O emission (ton/ha).

TABLE I
INPUT DATA FOR INDIRECT CO_2 EMISSION COMPUTATION

In rice farm operating machines	Energy required, MJ/kg	Lifespan, h	Net weight, kg	Field capacity, ha/h
Tractor	138	12000	1200	0.8
Rotary tiller	149	2000	200	0.8
Electric motor (irrigation pump)	150	5000	100	0.2
Mobile sprayer	150	5000	20	0.5
Combine harvester	116	3000	1300	0.62
In-field grain transport machine	116	3000	1100	0.84
Self-propelled straw baler	116	3000	900	0.5
Stubble cutting machine	149	2000	120	0.5

Source: Practical data 2021; CIGR 1999 [31]

Manufacturing of agricultural machines also indirectly emits GHG both from making materials and other activities, such as labor, transport, and repair. The energy required for making agricultural machines was from 116 to 180 MJ/kg, depending on the type of machines. It was 138 MJ/kg and 116 MJ/kg for tractor and combine harvester, respectively [31].

Indirect CO_2 eq. emission was computed as the following formula:

$$E_{CO2\ (in)} = \frac{E * W * f}{F_c * L_s} \quad (5)$$

Where: $E_{CO2\ (in)}$ is the indirect CO_2 emission (ton/ha), E is the energy required for manufacturing machine (MJ/kg), W is the weight of machine (kg), f is the CO_2 emission factor (f = 0.07), kg of CO_2 per MJ, F_c is the field capacity (ha/h), L_s is the life - span of machine (h). The lifespan of tractor is 12,000 hours (except for the second-hand units). It is 3,000 hours and 5,000 hours for combined harvester with field capacity of 0.62 ha/h and electric motor for irrigation water pump, respectively (Table 1).

III. Results and Discussion

A. Level of mechanization in rice farming

In Mekong Delta, operating stages in rice farming include land preparing and tillage, sowing and transplanting, cultivating, harvesting, and straw management. The scale of the field is one factor affecting the capacity and efficiency of using machines. A machine with a bigger capacity should be selected for a larger field size. In the case of three different Provinces in Mekong Delta, the average rice field size varies from 0.77 to 1.62 ha, derived from in-field measurements. Compared to other crops, application of mechanization is at higher Level for rice farming.

Besides traditional leveling methods, a laser-controlled land leveling system has been applied since 2004. In other operations, the tractor is the main traction source for most soil implements: plough, rotary tiller, and harrow. With the expansion in production scale and field size, drones for pesticide spraying have been applied as an alternative to mobile sprayers popularly used. Straw spread in the field by a combine harvester was collected using straw balers of mulched soil using straw choppers and rotary tillers.

In practice, the percentage of rice field area applied mechanization is different from stages. It is almost 100% for tillage, irrigation, and harvesting operations. On the other hand, it is still at lower Level for fertilizer spreading, pesticide spraying (using the same mobile sprayer), and transplanting operations [22]. At present, the application of drones for pesticide spraying has been developed in Mekong Delta (Fig.5). with a lot of advantages, such as high field capacity (4 ha/h), saving labor costs and pesticide amount compared to using shoulder sprayer; and health safety for farmers. In addition, mechanization in rice straw collecting has been developed using both tractor-hauled and self-propelled straw balers (Fig.6).

The highest value of MI_E is 99% for tillage and harvesting operations, which means that the application of these machines released most labor in operations. At lower levels, with the use of shoulder sprayers, it is about 80% for pesticide spraying and fertilizer spreading operations. In other words, the rate of human work is negligible compared to machine work.

Fig. 5 Drone used for pesticide spraying.

Fig. 6 Self-propelled straw baler

Similarly, the mechanization level in Mekong Delta rice farming fluctuates in different stages with a total of 3.17 HP/ha, using equation (2.2). In which the highest Level of

1.38 HP/ha is for tillage operation; the lowest Level of 0.03 HP/ha is for seeding and transplanting operations, as shown in Fig.7. In addition, it is also lower Level (0.04 HP/ha) for the two-fertilizer spreading and pesticide spraying operations.

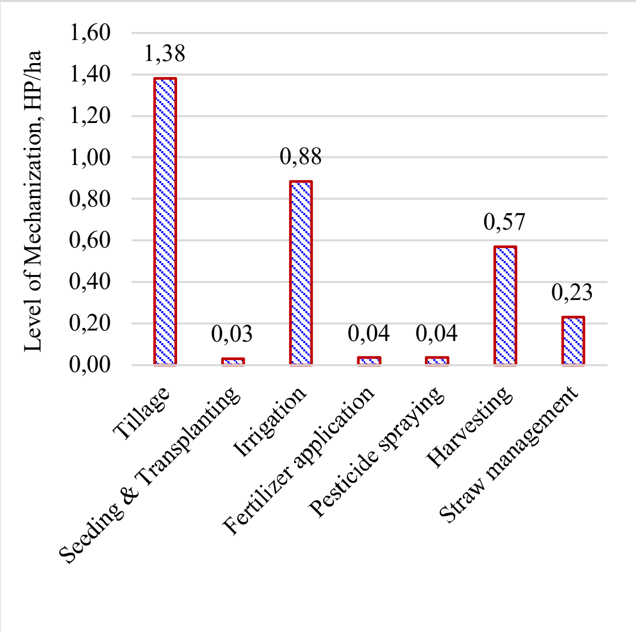

Fig. 7 Level mechanization of operations in rice farming

The application of machines in rice farming has a lot of advantages, such as a reduction in production cost, saving energy and input materials. However, it is also the cause of increased GHG emissions from burning fuel (direct emission) and manufacturing (indirect emission) of the machines, described in the following sections.

B. Direct CO_2 eq. emission

Direct CO_2 eq. emission was computed from the used amount of fossil fuel for the machines. The fuel consumption was converted to liter per ha (L/ha). In the tillage stage, fuel consumption was for all machines operating in land preparation, such as: ploughing, cultivating (rotary tiller), and harrowing. Fuel consumption and CO_2 and SO_2 eq. emissions in different operations in rice farming are shown in Table 2.

TABLE II

FUEL CONSUMPTION AND EQUIVALENT EMISSION IN RICE FARMING

Operations in rice farming	Fuel consumption, L/ha	CO_2 emission, kg/ha	SO_2 emission, kg/ha
Tillage	12.5	31.5	0.10
Seeding	1.5	3.8	0.01
Transplanting	4.3	10.8	0.03
Irrigation	20.0	50.4	0.16
Fertilizer application	1.5	3.8	0.01
Pesticide spraying	4.5	11.3	0.04
Harvesting	17.9	45.1	0.14
In-field transportation	6.0	15.1	0.05
Straw collection	8.7	21.9	0.07
Straw stubble cutting	4.5	11.3	0.04
Total	81.4	205.1	0.65

Corresponding to fuel consumption and electricity power of machines in rice farming, the total equivalent CO_2 emission was 0.21 ton/ha per cropping season. Compared to that in the Philippines, with the Level of mechanization at 2.31 HP/ha, the CO_2 eq. emission from fuel used for farming activities was 0.14 ton/ha per crop in irrigated areas [26], [32]. Combined with annual cultivated area and percentage of area applied mechanization, annual CO_2 eq. emission in different stages was computed and shown in Fig.8.

The emission is different from operations in rice farming; the highest is for harvesting operations, which combines harvester and in-field grain transport vehicles. Emission from irrigation operation takes the second place with the amount of 205,128 tons of CO_2 eq. per year.

Compared to other stages, although the emission of the two-fertilizer spreading and pesticide spraying operations were still at low Level, the more important factor is that it caused health problems for laborers. At present, thanks to the use of drones for pesticide spraying has been developed; it contributes to the health safety of farmers, increases field capacity (4 ha/h, in practice), and saves 50% of pesticide compared to manual spraying using mobile sprayers. With fuel consumption of 4.5 L/ha for each time of spraying and three applications per crop (estimated), it also saves about 138,460 tons per year for the whole cultivated rice field in Mekong Delta.

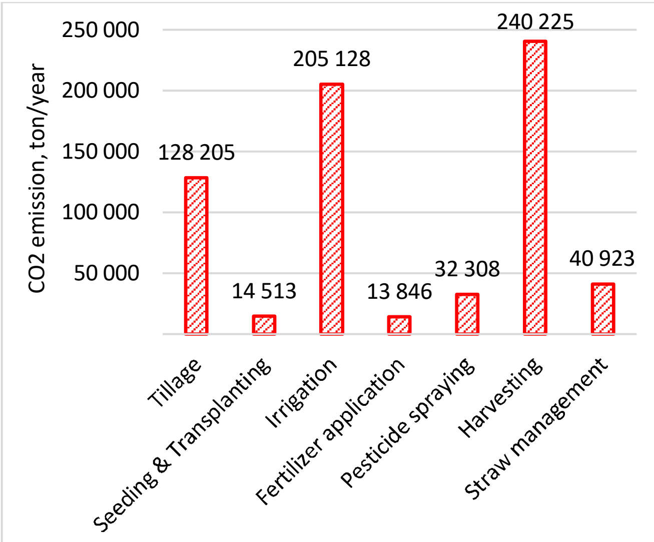

Fig. 8 Annual CO_2 emission from operations in rice farming.

C. Indirect CO_2 eq. emission

Besides the direct emission from fuel consumption, the manufacturing process of agricultural machines also releases GHG, which is considered as the indirect CO_2 eq. emission, which was computed as described in the Equation (2.4). Like the direct emission, it also fluctuates in different types of machines applied in rice farming (Fig.9) with the total indirect CO_2 eq. emission of 0.02 ton/ha, accounting for 8.5% of the total CO_2 eq. emission. With the cultivated rice area of 4.07 million ha in Mekong Delta, total annual CO_2 emission computed from application of machines in rice farming is 733,000 tons/year. Thus, it is necessary to mitigate the impacts of mechanization on GHG emission by increasing the efficiency of use and ensuring the quality of exhaust flue gas from engine of machines applied in rice farming. Application of straw balers contributes to reduce 20% amount of rice straw burned in the field in Mekong Delta, corresponding to 1.6 million tons of straw and 1.95 million tons of CO_2 eq. emission.

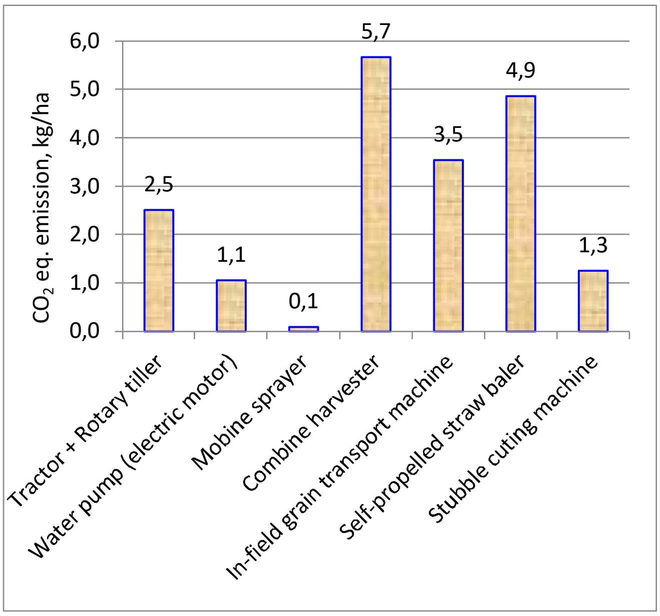

Fig. 9 Indirect CO_2 eq. emission from type of machines

IV. Conclusion

Agriculture is one of the sectors that contribute to the increase in greenhouse gases in our globe. Mechanization in paddy cultivation has been rapidly developed in Mekong Delta, with a power level of mechanization of 3.17 HP/ha. The application of high-tech equipment, such as drones for pesticide spraying, has also been promoted in recent years. The impacts of machines used in paddy production mechanization in the Mekong Delta on GHG emission have been studied.

The mechanization done for paddy production would obviously contribute to an increase in yield, reduction in production cost, losses in the harvesting process, and saving irrigation water and input materials. However, this issue leads to increased GHG emissions, both direct and indirect, because all machines use fossil fuel such as diesel oil and gasoline in their operation. Thus, together with the promotion of mechanization, it is necessary to consider the mitigation of GHG emissions of the paddy cultivation mechanization process by some approaches. These might be as application of machines with high power levels of mechanization, increasing the efficiency of use, and ensuring the quality of exhaust flue gas from the engine of machines applied in rice farming. The study results also show that the direct CO2 eq. emission in rice farming operations is 0.22 ton/ha per cropping season, and the indirect CO2 eq. emission is 0.02 tons/ha. With the paddy area of 4.07 million ha in the Mekong Delta, the total CO2 eq. emission from mechanization in paddy cultivation corresponds to 733,000 tons/year.

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