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# Assessment Environmental and Social Impacts for the Rice Straw Utilization Technical Models to Promote Circular Economy for Rice Production in Chau Thanh District - An Giang Province

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**Abstract**

*The study objective is to provide an initial scientific basis for calculating $CO_2$ equivalent ($CO_2e$) emission reduction from the three technical models such as rice-straw composting, rice-straw fermented for cattle feed, and straw mushroom production, which are rice-straw utilization alternatives instead of open burning them in Chau Thanh district. The study calculation is based on the surveyed practical database, the theoretical emission factors (EF), and the implementation of EasyPol-Ex software version 5 (Ex-Act) to estimate the amount of $CO_2e$ emissions when switching. The results show that in 2022, Chau Thanh could avoid 330,236 tons of $CO_2$ emissions by burning 171,637 tons of rice straw. The estimated amount of $CO_2$ emitted from harvesting and rolling rice straw by machine was 4.375 g $CO_2e$ per kilogram of rice straw. The EF for transportation of rice straw to model implementation places was 740 g$CO_2e$/kg. The additional EFs for mushroom, composting, and animal feed production models were 222g, 172g and 60g $CO_2e$/kg, respectively. Results indicate that although the EF of rice straw collection and transportation was still high, the total $CO_2e$ from three models (including transportation) was still lower than the EF from straw burning. In addition, farmers who own the paddy field earned an extra 500,000 VND/ha per crop, and farmers earned an extra about 1.7 to 2.3 million VND per crop, depending on the model applied. The successful implementation of technical models promoted the concept of circular economy applied to rice production industries.*

Keywords: $CO_2e$ emissions, open burning, rice straw, composting, mushroom, An Giang, circular economy.

## 1. Introduction

As one of the countries with continuously increasing GHG emissions, Vietnam also signed on to join the United Nations Framework Convention on Climate Change in 1992 (UNFCCC), which was ratified in 1994. By 2016, Viet Nam had developed the National Notification on Greenhouse Gas (GHG) Inventories and the Biennial Update Report (BUR) [1]. According to the results of the national GHG assessment, the total GHG emissions in Vietnam in 2016 were 316.7 million tons of $CO_2$, an increase of 212.9 million tons compared to those in 1994. It also estimates that $CO_2$ emissions will be 726.2 million tons and 927.9 million tons in 2025 and 2030, respectively. Among the assessed sectors, energy accounts for the largest proportion, i.e., 65% of the total national GHG volume in 2016, and also has the highest increase, about 180.2 million tons, from 1994 to 2016 [2]. Following energy sector, agriculture is the second main source of $CO_2e$ emissions, about 89.7 million tons of $CO_2e$, accounting for 31.6% of the total national GHG volume in 2014. Among agricultural $CO_2e$ emissions, the $CO_2e$ emissions from fertilizer and pesticide uses were the main concerns. A study in 2014 reported that there were six methods to treat rice straw such as burning, burying, mushroom cultivation, breeding, sale and giving to neighbors. The usage of rice straw varied seasonally. In the winter-spring season, straw burning is the most common activity (98.2%), which decreased to 89.7% in summer-autumn and 54.1% in autumn-winter. In addition, farmers also burn the rice straw at the paddy field, which created about 17.95 million tons of $CO_2$, 485.58 million tons of CO and 10.38 thousand tons of NOx [3]. According to the Decision No. 1693/KH-BNN-KHCN which approved the GHG Emissions Mitigation Plan (including methane) for the agricultural sector, the targeted reduction of $CO_2e$ in 2030 and vision to 2050 is 53.57 million tons of which 14.26 million tons resulted from crop farming and animal husbandry. Total methane emissions should not exceed 59 million tons $CO_2e$.

The total amount of rice straw generated in the Mekong Delta was about 26.2 million tons in 2011 and 30 million tons in 2021 and 30% of them was burned at the paddy field [4]. Rice straw burned in the field also causes GHG emissions (g/kg), including 1,147 ± 169 g of $CO_2$ [5], 0.7 - 4.1 g of $CH_4$ and

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0.019 - 0.057 g of $N_2O$ [6] per kg of dry rice straw. Emission factors (EF) for rice straw burning (g/kg) determined for PM, $CO_2$, CO, and $SO_2$ were 17 ± 3.8, 1,399 ± 228, 68 ± 22, and 1.5 ± 0.4, respectively [7]. A study of IRRI showed that the $CO_2e$ per ha converted from $CH_4$ and $N_2O$ in a rice crop season with straw incorporation emitted about 3,500 kg $CO_2e$ per ha, 1.5 times higher than the amount emitted from the practice of rice straw removal.

To achieve the national goals for GHG reduction, An Giang People Committees has developed and implemented the Strategy for effective management utilization of rice biomass to produce energy in the context of climate change toward 2030 vision [8]. The Strategy set up the target of 5% reduction of GHG emission from rice cultivation in 2020, and 1% per year until year 2030. To achieve the green growth and above GHG reduction target, the Strategy promoted the use of rice straw for mushroom production, composting and animal feeds instead of open burning as well as encouraged environmentally friendly agriculture practices by reducing fertilizer and pesticide usage. Chau Thanh District is one of pioneer districts in An Giang province to implement the three technical models to shift from rice straw open-burning to rice-straw composting, rice-straw fermented for cattle feed, and straw mushroom production since 2013. After 10 years of implementation, the project needs to be reviewed and assessed its impacts via GHG reduction and increase benefits to farmers. In order to answer this question, the study on assessment environmental and social impacts for the rice straw utilization technical models to promote circular economy for rice production in Chau Thanh District, An Giang was conducted in order to provide a scientific basis for calculating $CO_2e$ emission reduction and profits brought from each models. Thus, the study results can support the government to extend the effective models to other areas and to pursue their strategy and circular economic concept.

## 2. Study Subjects and Methods

### *2.1. Study Subjects*

This study focused on three technical models utilizing rice straw in An Giang such as: (i) straw mushroom production; (ii) rice straw composting; and (iii) fermented rice straw for animal feed which were shown more specifications in the 2.2.2.

Thirty households implementing the technical models in Chau Thanh District were selected randomly for interviewing with a prepared questionnaire. Data were collected including technical specification, amount of straw used, transportation distance of harvesting rice straw, price of rice straw rolls, price of materials and sale price of products, labor salary, energy consumption, profits, etc.

### *2.2. Study Methods*

#### *2.2.1. Statistical Data of Rice Production and Rice Straw*

Data on rice area, rice output, and rice yield were compiled from the survey results, the General Statistics Office of Vietnam and the statistical yearbook of An Giang province as shown in Table 1.

Table 1. Rice straw production in 2022

| Place | Rice area (ha/year) | Rice straw (ton/ha) | Straw production (ton/year) | Straw collection (ton/year) |
|---|---|---|---|---|
| Chau Thanh | 78,017 | 5.5 | 429,094 | 171,637 |
| An Giang | 605,537 | 6 | 3,633,222 | 726,644 |

In 2014, farmers started to collect rice straw, about 20% of total rice straw in paddy field and then increase to 40% (about 171,637 ton/year) in 2022. Chau Thanh now has 13 rolling machines used for harvesting and packaging rice straw.

#### *2.2.2. Studied Technical Models*

*Straw mushroom production model*: this indoor mushroom (*Volvariella volvacea*) cultivation as shown in Fig. 1 requires the same preparation process as the outdoor cultivation. Rice straw was sterilized at temperature greater than 70 °C and had moisture content of 65% before used. The special technique in Chau Thanh is the turn-around cylindrical mold with 40 cm width and 60 cm height surrounding the plastic pipe with a diameter of 27 mm, length of 15 cm of which 10 cm was installed under floor.

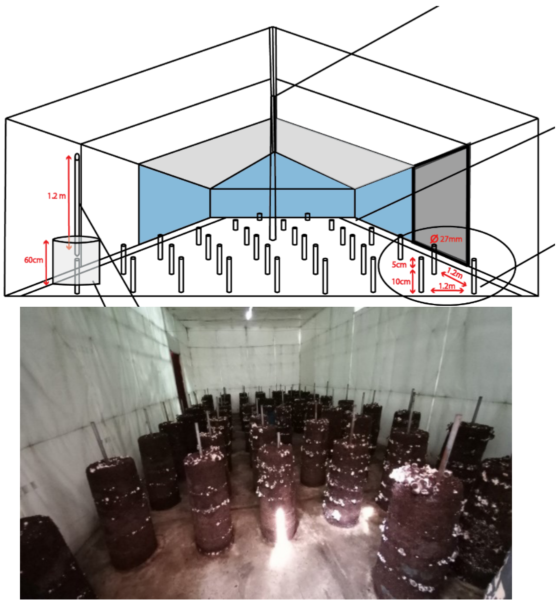


Fig.1. Straw mushroom production model.

*Fermented rice straw* for *cattle feed model:* Prepare 100 kg of rice straw mixed with 100 liters of clean water, 4 kg of urea and 0.5 kg of salt in plastic bags, fastened. After 7-14 days, when the straw became dark yellow, soft, without the smell of mold, took the fermented straw to dry in a cool place for 30-45 minutes to get rid of urea smell before feeding them to cattle. Provide animals with enough water to drink after eating.

*Composting model:* Prepare a flat ground or dig a 70 cm-depth to set up the compost container 3 x 3 x 1 m. Mix well the rice straw: manure: rice husk ash at weigh ratio of 1000: 300: 300 kg, then spread them evenly and spray an additional mixture of 3 kg *Trichoderma* and water on top surface. Finally, cover the container with a nylon bag to avoid wind and to maintain moisture. After 8 to 10 days, check the compost pile and add more water. After 20 days, check the moisture and mix the compost from outside to inside and re-cover, wait until 30 days when the compost turns to a loose black-brown manure, soft and humid mixture.

*2.2.3. Emission Factors (EF)*

This study applied the emission coefficient to estimate the total $CO_2e$ emission from open-burning rice straw and compare them with those from the three technical models.

Total $CO_2e$ emission from straw burning was calculated as follows:

$CO_2e$ emission (ton/year) = $A \times MB \times CF \times EF \times 10^{-3}$ (1)

in which: A is burning areas (ha/year), MB is straw production (ton dry weight/ha), CF is burning efficiency =0,80%, EF of IPCC as shown in Table 2.

The $CO_2e$ emission from the model will be calculated based on the total $CO_2e$ emission from harvesting, rolling and transporting the rice straw plus the additional $CO_2e$ emission of applied technical model compared with the traditional model.

Table 2. $CO_2$ Emission factors (g/kg of dry straw)

| Activities | $CO_2$ (g/kg) | $CH_4$ (g/kg) | $N_2O$ (g/kg) |
|---|---|---|---|
| Straw burning | 1,515 [a] | | |
| | 1,464 [b] | 2.7 | 0.07 |
| Machinery straw rolling | 4.375 [c] | | |
| Transportation | 504 (boat) | | |
| | 840 (truck) | | |

*Note:* [a] IPCC 2006; [b] [5]; ; [c] Emission from fuel consumption in practice in Chau Thanh District, 1.39 g diesel oil (DO)/kg rice straw, EF= 3.15 $kgCO_2$/kg DO.

The EF reported from other studies for straw burning, harvesting and transporting were shown in Table 2. In Chau Thanh district, straw transportation was mainly by 25 - ton boat and 15 tons truck with about 10 km distance. EF for transportation was 1.26 kg $CO_2e$/km from fuel consumption [8]. The straw collection rate in Chau Thanh district is 40%, of which 30% was transported by navigation and 70% was by road [9]. Thus, it needed 2,060 boat trips and 8,010 truck trips to transport all collected rice straw to farmers.

*Emission for straw mushroom production model:* Compared with the traditional outdoor mushroom production, the indoor mushroom model is required to control humidity and temperature, and therefore, requires more energy supplied for lightening, air ventilation and steam supplying.

+ Emissions from electricity used for lighting 5 days x 24 hours/day x $2x10^{-5}$ Mwh was:

$CO_2e$ Emissions = Electricity consumption × $CO_2$ EF of the grid (2)

The grid's $CO_2$ EF is 0.7221 tons of $CO_2$/MWh [10].

+ Emissions from burning 600kg of wood for providing steams to disinfect the mushroom houses in 10 hours for each crop (8 crops/year) was:

$CO_2e$ Emissions (g) = Wood consumption (kg) x EF (g/kg). (3)

where EF for wood burning is 1,520 g $CO_2$/kg; 5.06 g $CH_4$/kg; 0.06 g $N_2O$/kg [11].

*Emission for animal feed production model:* In this model, the GHG emission from the fermentation process is minor. But $CH_4$ emissions from the straw feed digestion in the cattle's rumen will be considered by using the Ex-Act software [12], when shifting from straw open burning to this model. Each year, Chau Thanh will apply this model for 20 livestock households, each household raised in averages 3 mature cattle. Results showed that its EF was 60 g $CO_2e$ per kg of straw.

*Emission for straw composting model:* GHG emission during composting process was calculated as following:

$CH_4$ Emission= $\sum_i (M_i \times EF\_CH4_i) \times 10^{-3} - R$ (4)

$N_2O$ Emission = $\sum_i (M_i \times EF\_N2Oi) \times 10^{-3}$ (5)

where $CH_4$, $N_2O$ emissions (tons/year); $M_i$ is the mass of straw (kg/year); *EF* is the emission factor; *R* is the total amount of $CH_4$ recovered during the study year (tons/year). However, when applying the composting model, there is no recovery of $CH_4$ generated, so $R = 0$. *EF* from straw composting was 4g $CH_4$ and 0.24g $N_2O$ per kg of wet straw weight [13]. $CH_4$ and $N_2O$ emission were converted to $CO_2$ equivalent ($CO_2e$) by applying GHG emission conversion coefficient to $CO_2e$, such as: $1CO_2 = CO_2e$; $1CH_4 = 25\ CO_2e$; $1N_2O = 298\ CO_2e$ [13].

*2.2.4. Cost-benefit analysis*

Total costs and profits are calculated based on the production costs and revenues [14] in each model, which could be calculated as follows:

$$TC = \sum_{j=1}^{3} \sum_{i=1}^{n} P_{ij} X_{ij} \quad (6)$$

$$TR = \sum_{j=1}^{3} Q_j P_j \quad (7)$$

where $i = i^{th}$ production input;

$j = j^{th}$ production crop in the year of production.

$TC$= total cost of the production model.

$TR$= total revenue of all crops of the production model.

$P_{ij}$= $i^{th}$ input variable price of crop $j$ in the model.

$X_{ij}$= amount of $i^{th}$ input variable of crop $j$ in the model.

$P_j$= price of product of crop $j$ in the model.

$Q_j$= quantity of product of crop $j$ in the model.

This study used the *TR:TC* ratio without applying discount rate as the *B:C* ratio to assess the economic results.

*2.2.5. Software method*

Study used EasyPol - Ex-ante carbon-balance tool version 5 (Ex - Act) software supported by FAO to calculate and assess $CO_2e$ emissions from husbandry [12].

## 3. Results and Discussion

### *3.1. Current Situation of Burning Rice Straw and Potential $CO_2e$ Reduction in Chau Thanh District and An Giang Province*

The open burning rice straw after harvest was a common traditional treatment in An Giang and in Mekong Delta provinces [2, 3]. Since 2012, when the rice by-products management strategies were issued and applied in Chau Thanh district in particular and in An Giang province in general, the percentage of rice straw collected and removed out paddy fields has increased gradually. After 8 years of strategy implementation (2014-2022), by the year 2022 this rate went up to 37 - 40% in Chau Thanh District, i.e. average rate is 5%/year [14]. 70% of straw collected was used for three models, indicating 15% for mushrooms, 5% for fermented feeds and 50% for composting, and the remaining 30% for stump cover of vegetables and orchards. According to the strategy, rice straw collection rate in 2030 should increase to 60% in Chau Thanh and 40% in An Giang, respectively [14], and the rate of mushroom: feed: compost model was planned as 35:15:50 in 2030.

With 257,456 tons of straw collected in year 2030, Chau Thanh could avoid burning and therefore can reduce $CO_2e$ emission about 330,236-ton $CO_2e$/year (in 2022: 171,637 tons collected straw and 220,157 tons $CO_2e$/year) (Table 3). Those figures for An Giang Province were 932,058 and 1,864,116 tons $CO_2e$ in 2022 and 2030, respectively.

Table 3. Total $CO_2e$ reduction from avoiding straw burning in 2030 in Chau Thanh

| Activity | GHG emissions (tons/year) | | | Total $CO_2e$ (tons/year) |
|---|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_2O$ | |
| Burning straw | 312,037 | 13,903 | 4,296 | 330,236 |

### *3.2. Estimated EF of $CO_2e$ Emissions for Alternative Utilization of Rice Straw*

Following the calculation methods in section 2.2.3 the emission factors of $CO_2e$ emitted from straw utilization will be discussed in the following sections.

Table 4. Estimated EF of $CO_2e$ (g/kg) for collecting and transporting rice straw in Chau Thanh

| | EF of $CO_2e$ ($gCO_2e$/kg straw) | Note |
|---|---|---|
| Straw collection | 4.375 | Fuel for rolling machine |
| Straw transportation | 740 | In average from Table 2 |

*3.2.1. Emission from mushroom production*

We estimated the total $CO_2e$ for one typical mushroom house as shown in Table 5. Each mushroom house used 5 lighting bulbs for 960 hours and 600 kg of wood for disinfection per year. It also consumes 4.8 tons of rice straw per year. Therefore, the EF for mushroom production was 222 g $CO_2e$ per kg of straw per year.

Table 5. Total $CO_2e$ for one typical mushroom house

| Emission from burning wood | EF ($gCO_2$/kg) | Total emission (kg/year) | $CO_2e$ emission (kg/year) |
|---|---|---|---|
| $CO_2$ | 1,520 | 912 | 912 |
| $CH_4$ | 5.06 | 3.036 | 75.9 |
| $N_2O$ | 0.06 | 0.036 | 10.7 |
| Emission from lighting | EF $kgCO_2$/kwh | | |
| $CO_2$ | 0.7221 | 69.3 | 69.3 |
| **Total** | | | 1,067.9 |

*3.2.2. Emission from straw compost production:*

Based on (4) and (5), the EF of straw composting was converted to $CO_2e$ such as:

Table 6. Estimated $CO_2e$ emission from straw composting

| Emission from composting | EF (g/kg) [12] | EF ($gCO_2e/kg$) |
|---|---|---|
| $CH_4$ | 4 | 100 |
| $N_2O$ | 0.24 | 71.5 |
| $CO_2e$ | | 171.5 |

### *3.3. Estimated Potential Reduction of $CO_2e$ Emissions in Chau Thanh and An Giang*

Results in Fig. 2 indicated that EF of straw burning (e.g. 1,282 $gCO_2e/kg$ straw) is higher than EF emission from three models. Thus, instead of burning, rice straw should be collected and used in any model. The mushroom production model had the highest EF, followed by compost model and then animal feed model. However, EF of straw collection and transportation was still high, 744 $gCO_2e/kg$ straw, 58% of burning straw. Chau Thanh needs to find more efficient transportation means in order to reduce transportation EF. The maximum transportation distance from paddy fields to the model locations should not more than 15 km.

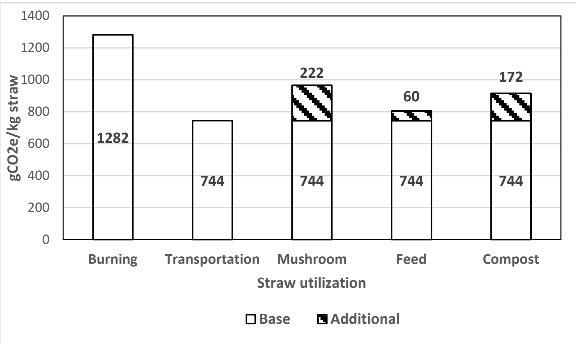


Fig. 2. Comparison of estimated emission factor $CO_2e$ ($gCO_2e/kg$ straw) between burning and other straw utilization activities.

Apply the EF in Fig. 2 for the existing conditions in 2022 and 2030 vision of rice utilization in Chau Thanh and in An Giang, the estimated total $CO_2e$ reduction for shifting from straw open-burning to the three models was explored in Table 7. The total $CO_2e$ reduction was equivalent to $CO_2e$ reduction from avoid burning plus to $CO_2e$ emission from applied models because the productions of mushroom, compost or feeds from other substrates also create GHG. Results in Table 7 indicated that Chau Thanh could cut off 330,421 and 566,101 ton $CO_2e$ in year 2022 and in 2030 if they implement the rice-byproduct utilization strategy. If this strategy was applied successfully in An Giang province, the whole province can reduce 3,195,528 tons $CO_2e$/year in 2030.

Table 7. Estimated $CO_2e$ reduction potentials (ton $CO_2e$ /year) from shifting to other straw utilizations

| | **Chau Thanh** | | **An Giang** | |
|---|---|---|---|---|
| **Straw utilization** | **2022** | **2030** | **2022** | **2030** |
| **Avoid burning** | 220,039 | 330,059 | 931,558 | 1,863,116 |
| **Mushroom model** | 24,880 | 87,080 | 105,332 | 491,548 |
| **Feed model** | 6,903 | 31,064 | 29,225 | 175,348 |
| **Composting model** | 78,599 | 117,899 | 332,758 | 665,515 |
| **Total** | 330,421 | 566,101 | 1,398,872 | 3,195,528 |

### *3.4. Assessment of Socio-Economic - Environmental Benefits When Applying the Model*

*3.4.1. Economic Benefits*

Farmers who own the paddy field earned extra 300,000-500,000 VND/ha per crop, i.e. increase of 10 % of income, equivalent about 11.8 M $ USD per year in An Giang. Further, straw collection could create the jobs, which brought 1,200,000 - 1,500,000 VND/ha for salary and 2,500,000 VND/ha profit from sale rolled straw.

Table 8 shows the estimation of economic benefits for straw utilization models in Chau Thanh in 2022. A 40 $m^2$ mushroom house had the capital cost of 29 million VND which could last for 12 crops or 18 months. Its operation cost was 7,281,032 VND/crop and could provide 130 kg mushroom per crop and 2,118,968 VND/crop. Chau Thanh used 25,746 tons of straw for mushroom production model in 2022, which brought about 101 billion VND/year. The composting model of 4,000 kg straw mixed with cow manure, rice husk ash, and *Trichoderma,* which cost about 16,880,000 VND, could earn 2,320,000 VND. Chau Thanh used 85,819 tons of straw for composting model in 2022, which brought about 49 billion VND/year. The fermented straw for animal feed model helped to reduce labors for grass harvest, increase percentage of digestibility by 10-15% compared to eating raw dried straw; increase amount of crude protein in the straw by 2.5 times, therefore, cattle gain more weight quickly, brought higher economic efficiency. The study did not calculate such profits yet. The revenue for this model only counted for saving the labor from grass harvest to earn higher incomes. In practice the revenue from this model could be much higher than the figure used in Table 8.

Table 8. Estimated economic benefits for straw utilization models in Chau Thanh in 2022

| Typical models | Mushroom house (40 $m^2$-540 kg straw) | Animal Feeds (7.2 ton straw) | Composting model (4000 kg straw) |
|---|---|---|---|
| Capital cost (VND) | 29,199,030 | 580,000 | 6,080,000 |
| Operation cost (VND/crop) | 7,281,032 | 12,160,000 | 10,800,000 |
| Revenue (VND/crop) | 9,400,000 | 14,500,000 | 19,200,000 |
| Profit (VND/crop) | 2,118,968 | 1,760,000 | 2,320,000 |
| Straw used per model (ton/year) | 4 | 7,2 | 4 |
| Amount of used straw (ton/year) | 25,746 | 8,582 | 85,819 |
| Total Profit (Million VND/year) | 101,026 | 2,098 | 49,775 |
| Ratio B:A | 0.23 | 0.14 | 0.14 |

The results in Table 8 showed that the *B:C* ratio of mushroom models was the highest (0.23). The fermented straw animal feed model brought the lowest total profits because Chau Thanh did not raise many cattle. The composting model did not have a high *B:C* ratio like mushroom model, however, it was the traditional treatment measure of rice straw in An Giang.

### *3.4.2. Social benefits*

Social and gender equities were enhanced because the strategy and its support gave priority to poor people and those who live in vulnerable areas such as rural areas. The government supported Chau Thanh 2 rolling machines in the beginning of strategy implementation period. Later, farmers bought new ones for their own and brought the total number of machines to 13 after 5 years. Development of three models helped to create more job demands, mobilized the idle labors, and promoted women roles in rural families when women have opportunities to work at home for mushroom cultivation and husbandry, and therefore, improved social life and living quality. It also helped to avoid migration to city for job demands.

### *3.4.3. Environmental benefits*

Avoiding burning rice straw also means eliminating air pollution sources and reducing $CO_2$ emissions and minimizing other negative induced impacts. The implementation of three models stimulated the development of environmentally friendly agricultural practices. Rice straw and rice husk used to be considered agricultural wastes for a long time, but now they can be used as material sources for other production processes.

## 4. Conclusions and Recommendations

The results showed that the application of three technical models brought a significant reduction of CO2e, about 330,421 tons of $CO_2$e in Chau Thanh District in 2022. The study did not conduct any experiments to measure GHG emissions in practice and was almost based on emission factors and calculation software to estimate the $CO_2$ reduction when switching to three models. However, study results proved that the three models were suitable "carbon neutral" means to replace straw open-burning, indicating that all EFs are lower than EFs from open-burning. The EFs used in the study were issued by the Ministry of Natural Resources and Environment in 2020 [15] and IPCC (2006) [11], but the practical rice cultivation and the specification of three alternative models significantly affected the calculation results. Therefore, the investigation of farmers for input data was important. The EFs used in this paper were only considered for Chau Thanh and An Giang conditions; therefore, further studies should continue to survey and collect systematically statistical data sources in order to reflect the comprehensive social and economic impacts brought by the technical model applications. It was also noted that among the three rice crops per year, autumn-winter was not suitable for open burning, and summer-autumn was not perfect for harvesting and removing rice straw because of straw moisture and soil conditions. Therefore, the practice of the three models also depends on the weather, market demand, idle labor conditions, and agricultural activities.

Switching from straw open burning to implementation, three models confirmed the meaningful socio-economic and environmental benefits to the local residents, as well as the improved efficiency of the straw management strategy in An Giang. An Giang province will continue to expand the technical model application throughout the whole province and neighboring provinces to fulfil their targets in strategic vision 2030. An Giang province has pushed up an agricultural intensive promotion program, enhanced the local budget, extended the farmer networks to spread out the models, and applied the virtual circular economy concepts to rice production industries [16].

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