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Applied Geography and Geoinformatics for Sustainable Development

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Contents

Greenhouse Gas Emission Inventories Across Industrial Sectors in an Emerging Mekong Delta City

Diep Thi Hong Nguyen, Pham Thi Bich Thao, Phan Kieu Diem, Nguyen Kieu Diem, Nigel K. Downes, Can Trong Nguyen, Ho Ngoc Linh, and Nguyen Xuan Hoang

Abstract This study quantifies the greenhouse gas (GHG) emissions in 2019 for the industrial sectors of Can Tho City, Vietnam. Employing a bottom-up methodology, we estimated both direct and indirect GHG emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) resulting from fuel combustion. Data on source-specific fuel consumption was collected for individual industrial facilities, with emission factors adopted from international and regional guidelines. The result showed that in 2019, GHG emissions from industrial sources in the four districts of Cai Rang, Binh Thuy, O Mon, and Thot Not were approximately 16,788; 2,371,936; 2,870,543; and 14,965 tons of CO_{2eq}, respectively. The major contributions of GHG emissions were from the combustion of coal, firewood, rice husk, diesel oil, and fuel oil in the textile industry, paper, ink, food processing, beverages, tobacco, and construction materials. The research findings provide critical updates on the GHG emission inventory of Can Tho City and inform policymakers about targeting emission reduction measures.

Keywords Industrial sectors · Greenhouse gas emissions · Can Tho City · Mekong Delta · Emission inventory · Climate change · Rapid industrialization · Vietnam

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1 Introduction

Global warming is a phenomenon of increasing average near-surface air temperatures of the Earth over the past one to two centuries, resulting in adverse impacts on human beings and all other forms of life on Earth. According to the Intergovernmental Panel on Climate Change (IPCC) in 2013, methane (CH_4), though relatively short-lived compared to carbon dioxide (CO_2), possesses a significantly higher global warming potential (GWP) over a shorter time horizon, making it a potential contributor to global warming [1]. Nitrous oxide (N_2O) even boasts a greater GWP and can linger in the atmosphere for centuries, amplifying its climate change impact. Climate change has been recognized as one of the global issues requiring each country to jointly mitigate its greenhouse gas (GHG) emissions through Nationally Determined Contributions (NDC) [2]. In its updated NDC submitted to the UNFCCC (United Nations Framework Convention on Climate Change) in September 2020, Vietnam committed to reducing GHG by 9% unconditionally by 2030 below the Business As Usual (BAU) level and targeted a conditional 27% reduction in emissions below the BAU levels based on international support [3]. A lancet study has indicated the benefits of the NDC's goal of saving lives. In particular, approximately ten million lives will be saved annually by 2040 if countries raise their climate ambitions [4].

In 2018, the United Nations Environment Program suggested a list of intervention measures ranked to substantial improvement in air quality by identifying three categories including conventional, next-stage air quality, and development priority measures. The measures focused mainly on emission sources including large industrial and power plants, household and commercial sectors, road transport, agriculture, waste burning, and forest fires [4].

The industrial sector is the third largest source of direct GHG emissions [5], which is potentially vulnerable to climate change, especially to the impacts of extreme weather. Factories can adapt to these potential impacts by designing facilities that are resistant to projected changes in weather and climate, relocating plants to less vulnerable locations, and diversifying raw material sources, especially agricultural and forestry inputs. Industry is also vulnerable to the impacts of changes in consumer preference and government regulation in response to the threat of climate change. Factories can respond to these threats by mitigating their emissions and developing lower-emission products (high agreement, much evidence).

Industrial parks are characterized as a designed cluster of industries to meet the compatible demands of different organizations within one location [5, 6]. Industrial agglomeration has proven to be vital to the economic growth of developed countries and those of less-developed countries [7, 8]. Collecting the most important factors of production in the region, an industrial park usually represents the development level of specific industries in the region. Therefore, the industrial park should be regarded as the base unit for developing the industrial economy and also a breakthrough for regional resource allocation and environmental management. With the emergence of a low-carbon economy, more and more industrial parks are seeking a low-carbon mode incorporating production, consumption, and resource allocation issues.

Emissions from the industrial sector accounted for 30% of total global GHG emissions, which arose mainly from material processing, i.e., the conversion of natural resources (oil, biomass) or scrap into materials stocks which are then converted in manufacturing and construction into products [9]. Production of iron and steel and non-metallic minerals (predominantly cement) results in 44% of all CO_2 emissions (direct, indirect, and process-related) from the industry. Other emission-intensive sectors are chemicals (including plastics) and fertilizers, pulp and paper, non-ferrous metals (in particular aluminum), food processing, and textiles [8]. With the ongoing development, the industrial sector in Vietnam in general and in emerging cities in particular has undergone great expansion in coming years. This enables economic growth and at the same time poses risk to the environment through fuel consumption in industrial facilities. The mitigation roadmaps are essential to guide the industrial sector toward a low-carbon development approach. This, in turn, required an insightful understanding of source characteristics through emission inventory analysis.

The overarching objective of this study is to estimate emission sources of GHG emissions (i.e., CO_2, N_2O, and CH_4) in Can Tho City from four industrial zones in O Mon, Cai Rang, Binh Thuy, and Thot Not districts (Fig. 1). The outcome of this

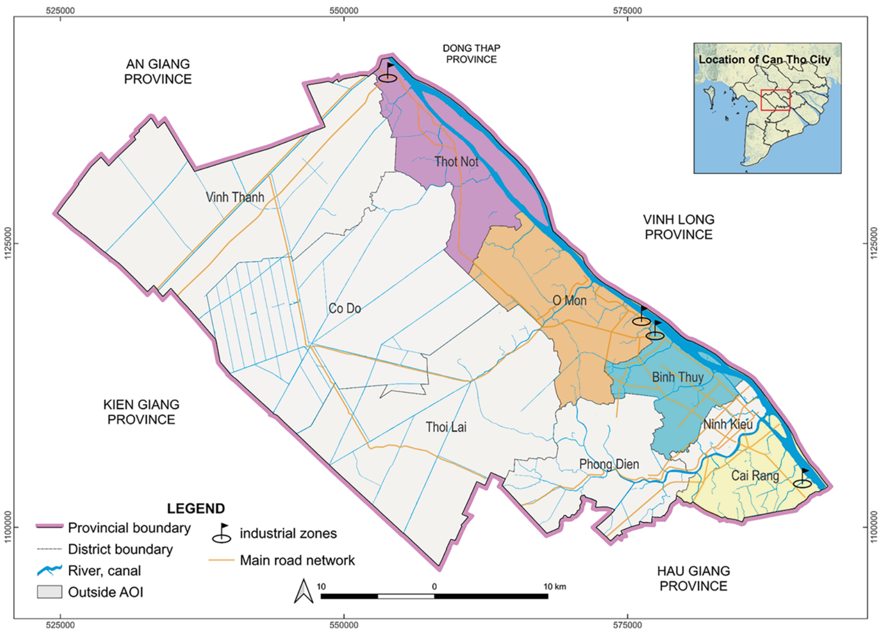

Fig. 1 Map of O Mon, Cai Rang, Binh Thuy, and Thot Not districts in Can Tho City and location of corresponding industrial zones (indicated by black flags)

study could be used as a reference to support policymakers in developing mitigation strategies, specifically for the industrial sector in Can Tho City.

2 Materials and Methods

2.1 Approach to Estimate Emission Inventory

An emission inventory is a comprehensive listing of the number of air pollutants emitted by various sources in a geographic area over a specific period. In general, two approaches have been applied to emission estimation: top-down and bottom-up. The top-down approach employs generalized factors such as total fuel consumption and emission factors. Emissions of specific plants were then allocated using variations of emission indicators such as fuel use or installed capacity. On the other hand, the bottom-up approach employs source-specific information such as fuel consumption and a stack test of individual plants. Although the latter is preferred since it describes more details of emissions, it requires comprehensive source-specific data including stack measurements. In this work, the bottom-up approach was used where the emission magnitude of a species was calculated as a function of a process emission factor and its intensity based on activity data (A) of a specific fuel and industrial facility, as described in Eq. (1) [10]:

$$E = \sum_m \sum_n A_{m,n} \times \mathrm{EF}_{m,n} \tag{1}$$

where E is the emissions (ton/year); A is the activity rate (TJ of fuel consumption or production); EF is the unabated emission factor (ton/TJ); m and n are fuel and industrial facilities.

The main types of GHGs are CO_2, CH_4, and N_2O, which are mostly emitted from fuel-using production activities, e.g., kilns and boilers. It should be noted that we only focus on GHGs directly from fossil fuels consumed in industrial production processes rather than related activities such as transport and logistics. All emissions of different gases were then calculated and converted into units of CO_2 equivalent (CO_{2eq}).

2.2 Fuel Consumption Data

Fuel types used for industrial facilities in four industrial zones in Can Tho City are relatively diverse including rice husk, wood, liquefied petroleum gas (LPG), charcoal, fuel oil (FO), and diesel oil (DO). There are 23 industrial facilities in Can Tho City, which are classified as textile, paper, ink, processing foods, beverages, and

Table 1 GHG emission factors from emission sources [8] (unit: kg/TJ)

	GHG		
Fuel type	CO_2	CH_4	N_2O
LPG	63,100	10	0.6
Diesel oil	74,100	3.0	0.6
Rice husk	106,000	1.0	1.5
Coal	96,100	1.0	1.5
Wood	112,000	30	4.0
Fuel oil	77,400	10	0.6

tobacco, and construction material. The fuel consumption by fuel and industrial types was collected from the Can Tho Export Processing and Industrial Zones Authority (CEPIZA) and Environmental Protection Division, Department of Natural Resources and Environment, of Can Tho City [11]. The data is available daily (eight facilities), monthly basis (five facilities), and annual basis (ten facilities). The data was converted to an annual basis to estimate annual emissions for peer comparison between facilities.

2.3 Emission Factors

An emission factor (EF) is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. Such factors facilitate the estimation of emissions from various sources of air pollution. According to the US EPA, the emission factors could be developed locally through a Continuous Emissions Monitoring System or stack sampling to reflect the actual operating condition of the local facilities. Database of EFs, in particular, the GHG, one could be obtained from EF databases such as [8]. In addition, emission inventory workbooks, developed for the Asian region, are counted as alternative sources including the Atmospheric Brown Cloud Emission Inventory Manual (Table 1). In this study, the emissions factor was adopted from various sources in consideration of the fuel and industrial characteristics in Can Tho city [8, 12].

Global warming potential (GWP) is used to compare the warming effect of different greenhouse gasses. The value of GWP was extracted from the IPCC report [13], which is described as detailed of 1 ton CH_4 is equal to 25 tons CO_{2eq} and 1 ton N_2O is equal to 298 tons CO_{2eq}.

3 Results and Discussion

3.1 Fuel Consumption in Industrial Zones

The total fuel consumption information (Table 2) indicates that the main fuels used for the industrial activities in Can Tho City were rice husk and diesel oil. There were 16 out of the total 23 companies and factories in this study that used rice husk during the production process. The main reasons for using this fuel source are its low cost and the availability of supplies from mills in the surrounding provinces. The total amount of rice husk used for boiler activities in 2019 was 2867 ktons. For example, enterprises in food processing, beverages, and tobacco products used 1.8 ktons of rice husk per year. Besides, factories in industrial zones use diesel oil to the same high degree.

3.2 GHG Emission from Industrial Zones in 2019

It was found that in the year 2019, GHG emissions from industrial zones in Can Tho City, Vietnam, were 5274 ktons CO_{2eq}, which are 5250.56 ktons CO_2 as CO_{2eq}, 1.61 ktons CH_4 as CO_{2eq}, and 22.06 ktons N_2O as CO_{2eq}. This included the direct emissions from fuel combustion for boilers. In addition, the industry consumes DO and gasoline for transportation off-road for the operating activity within the facility. Moreover, the facility also emitted indirect emissions through electricity consumption and waste generation; however, those indirect emissions were not included in this work.

The GHG (CO_2, N_2O, CH_4) is mainly emitted from the combustion of fuels such as coal, firewood, rice husks, and DO oil during the boiler operation. Specifically, of the GHG, the gas of CO_2 emissions is mainly found during the burning process of rice husk, while it mainly exhausted when using the coal-fired boiler. The exhaust gases from the oil-fired boilers of DO and FO are the following gases: CO_2, CH_4, N_2O, and other gases (i.e., CO, NO_x, SO_2, SO_3) and water vapor. The CO_2 emission

Table 2 Total fuel consumption in boiler operation (unit: ktons/year)

Fuel types	Industrial zone in Binh Thuy	Industrial zone in O Mon	Industrial zone in Thot Not	Industrial zone in Cai Rang	Total
Rice husk	992.42	1854.62	9.13	10.95	2867.12
Wood	1.83	–	–	–	1.83
LPG	0.21	0.13	–	–	0.34
Charcoal	–	–	0.35	–	0.35
Fuel oil (FO)	1.12	–	–	–	1.12
Diesel oil (DO)	0.02	9.91	–	–	9.93

from fuel combustion is mainly reported, while the CH_4 and N_2O are very low emissions. Among these sources, rice husk contributes the highest amount of GHG in comparison to the other sources.

3.3 GHG Emissions Attributable by District

Among districts, O Mon district has the largest contribution of GHGs from industrial zones, whereas the emission was 2870.54 ktons of CO_{2eq}/year accounting for 54.43% of total GHG emission from industrial sources in Can Tho City in 2019 (Fig. 2). Binh Thuy district takes second place in GHG emissions with 2371.94 ktons of CO_2eq/year, accounting for 44.97% of the total emissions. The presence of the Industrial Zone at O Mon and Binh Thuy district was the main source of these GHG contributions. Industrial zones in Cai Rang and Thot Not districts were established in 2005; therefore it is still in development and still has fewer industrial facilities. By 2019, industrial zone in Cai Rang district only had 12 industries, and industrial zone in Thot Not only had eight industrial facilities.

The main emission sources of industrial zones in the four districts are LPG, firewood, charcoal, rice husk, fuel oil (FO), and diesel oil (DO). For example, the GHG emitted by burning rice husk in processed foods, beverages, and tobacco in O Mon, Binh Thuy, Cai Rang, and Thot Not districts were 2843.50, 2364.51, 16.79, and

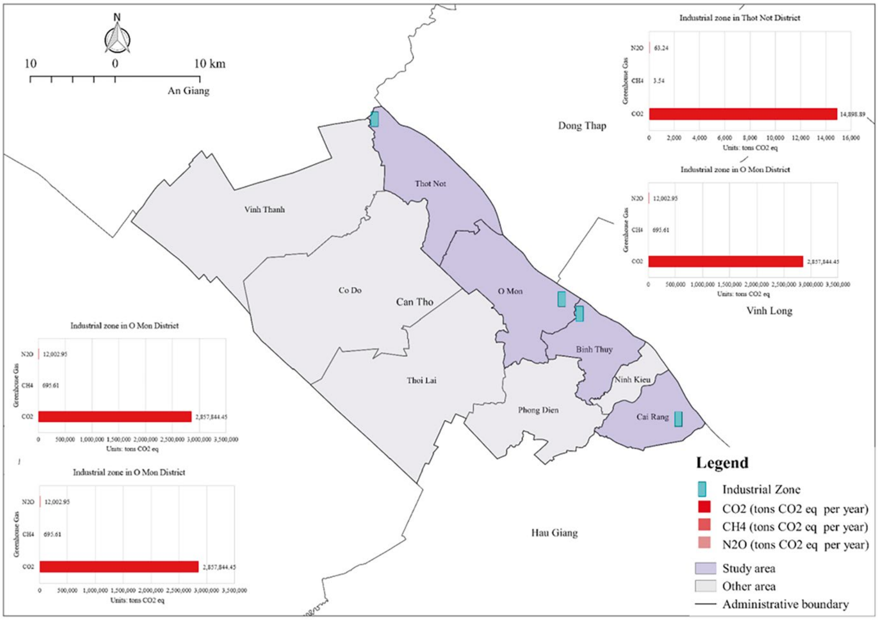

Fig. 2 Greenhouse gas emissions in Industrial Zones of Can Tho City in 2019

13.99 ktons of CO_{2eq}/year, respectively. In addition, the emissions due to diesel oil consumption were also high and concentrated mostly in Binh Thuy district, emitting 26.82 ktons of CO_{2eq}/year.

3.4 GHG Emissions Attributable by Industrial Type

The GHGs from processed foods, beverages, and tobacco processing industry are the highest contributor, accounting for 99.86% of total emissions which is higher than three times the other three industrial zones (emitting 5266.97 ktons of CO_{2eq}/year). Among GHG types, emitting from CO_2 takes the highest amount of emission, accounting for 5243.37 ktons of CO_{2eq}/year. Due to the needs of the domestic market and exports of processed foods, beverages, and tobacco, factories have to increase the boilers and kilns capacity (1500 tons/h) and amount of fuel burned during operation (48 tons rice husk/day).

Two districts of Cai Rang and Thot Not shared much lower emissions of GHG than Binh Thuy and O Mon (Table 3). The GHG emissions of the same industry sector in Thot Not and Cai Rang district were lower than in Binh Thuy and O Mon. For example, the GHG emissions from processed foods, beverages, and tobacco industry were 16.79 ktons of CO_{2eq}/year in Cai Rang district and 13.99 ktons of CO_{2eq}/year in Thot Not district, while the emissions were about 2870.54 ktons of CO_{2eq}/year in O Mon and 2365.64 ktons of CO_{2eq}/year in Binh Thuy (Table 3, Fig. 2). The reason is that industrial zones in O Mon and Binh Thuy districts were formed very early in 1995 and 1998, which were invested and fully occupied by many factories. Currently, the area of industrial zones of Binh Thuy and O Mon districts has been built up, while the industrial zones of Cai Rang and Thot Not

Table 3 GHG emissions by district in Can Tho City (unit: ton CO_{2eq}/year)

Industrial zone	Manufacturing	CO_2	CH_4	N_2O
Industrial zone in Binh Thuy	Paper, ink	4939.76	22.29	41.84
	Processing foods, beverages, and tobacco	2,354,883.78	884.68	9876.37
	Textile industry	1282.18	0.30	5.40
	Subtotal	**2,361,105.72**	**907.26**	**9923.61**
Industrial zone in O Mon	Processing foods, beverages, and tobacco	2,857,844.45	695.61	12,002.95
	Subtotal	**2,857,844.45**	**695.61**	**12,002.95**
Industrial zone in Cai Rang	Processing foods, beverages, and tobacco	16,714.08	3.94	70.48
	Subtotal	**16,714.08**	**3.94**	**70.48**
Industrial zone in Thot Not	Construction material	970.49	0.25	4.51
	Processing foods, beverages, and tobacco	13,928.40	3.29	58.73
	Subtotal	**14,898.89**	**3.54**	**63.24**

districts were formed in 2005 later than Binh Thuy and O Mon so the technical infrastructure is not enough to attract domestic and foreign investors. In addition, due to a recent establishment, more advanced equipment was employed in industrial zones in Cai Rang and Thot Not districts, compared to those in Binh Thuy and O Mon districts, which helps to reduce a part of emissions during the industrial operation.

3.5 Uncertainty

Uncertainty analysis is important for emission inventory. In the context of this study, it was somewhat difficult to provide a quantitative assessment of the uncertainties. Therefore, the discussion of uncertainties will be provided qualitatively. Customarily, the uncertainty of emissions is due to activity data and emission factors. The activity data was collected representative of individual facilities in each industrial zone and submitted to the government. Therefore, it is considered that the data has properly passed quality control and quality assurance. On the other hand, the emission factors were obtained from the literature review from standard international recommendations. Though the emission factor was not specific to the study site which can raise uncertainties, the approach was considered the best available, and the uncertainties resulting from [8] emission factor are universally accepted.

The electric consumption from industrial facilities is significant due to the operating system that involves lighting and other producing systems. In this work, the indirect emissions were not included in the investigation and should be included in future work to fully assess the level of greenhouse gas emissions in the industrial sector. This is to provide basic information to provide strategies to reduce emissions at the same time as industrial expansion.

3.6 Policy Implication

According to the results, processing food, beverages, and tobacco are the key sources of emissions from the industrial sector in Can Tho City. Rice husk remains the key contributor to GHG emissions in the city due to the process of food, beverages, and tobacco production. Based on the results of research on key emissions sources as well as considering existing solutions applied in literature, practical solutions to promote industrial greening for industries operating in industrial zones in the study area will be discussed.

For the enterprises: First of all, to effectively reduce GHG emissions, the optimization of the production process to ensure optimized production conditions in terms of raw material consumption, production, and generation of waste and manufacturing process parameters such as furnace melting temperature, time, speed, etc. need to be monitored, maintained, and calibrated as close to optimal conditions as possible, making the production process reach the highest efficiency with the best productivity.

For the authorities: Intensification of regular inspection of enterprises using boilers and fines for violations. It is also necessary to have policies and incentives to support businesses so that small and medium enterprises have the opportunity to change outdated technology and invest in environmental protection. Encourage the businesses to plant trees around the production area to create a green buffer zone and landscape to improve the quality of the air environment.

4 Conclusion

The GHG emission was investigated in four industrial zones including Thot Not, O Mon, Binh Thuy, and Cai Rang, Can Tho City. Fuel types used in these industrial activities were rice husk, wood, LPG, charcoal, fuel oil (FO), and diesel oil (DO) in which diesel oil and rice husk were most frequently used. The results of GHG emissions in the textile industry; paper and ink; processed foods, beverages, and tobacco; and construction materials were 1288; 5002; 5,267,599; and 975 tons of CO_{2eq}/year, respectively. As can be seen, the highest greenhouse gas emissions were in the sectors of food, beverage, and tobacco. The findings revealed that GHG emissions in the industrial zones in four districts of Cai Rang, Binh Thuy, O Mon, and Thot Not in Can Tho City were 16,790; 2,372,191; 2870,915; and 14,899 tons of CO_{2eq}/year, respectively. Future studies should focus on GHG emissions in other sectors, for example, agriculture, aquaculture, and environmental treatment facilities. Alternative technology and fuel efficiency should be applied to reduce GHG emissions.

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Conflicts of Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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