INITIATIVE ON
Low-Emission
Food Systems

Characteristics of the aquatic food system in Can Tho (the Mekong Delta), Vietnam and its emission profile

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Contents

List of abbreviations

ASC	Aquaculture Stewardship Council
ASEAN	Association of Southeast Asian Nations
BAP	Best Aquaculture Practices
BMP	Better Management Practices
CDM	Clean Development Mechanism
CH4	Methane
CO2	Carbon dioxide
COP27	The 27th Conference of the Parties to the United Nations Framework Convention on Climate Change
EI	Emission Intensity
EPCs	Export and processing companies
FAO	Food and Agriculture Organization
FCR	Feed conversion rate
FTA	Free Trade Agreement
GAFS	Gender in Aquaculture and Fisheries Section
GAP	Good Agriculture Practices
GAP	Gender action plan
GDP	Gross Domestic Product
GHG	Greenhouse gas
GlobalGAP	Global Good Agricultural Practice
GRDP	Gross Regional Domestic Product
ICAFIS	International Collaborating Centre for Aquaculture and Fisheries Sustainability
ILO	International Labour Organization
IMTA	Integrated multi-trophic aquaculture
IPCC	Intergovernmental Panel on Climate Change
KH-UBND	Plan of the People's Committee
LLs	Living Labs
LL4P	Living Labs for People
LULUCF	Land Use, Land-Use Change and Forestry
MARD	Ministry of Agriculture and Rural Development
MOF	Ministry of Finance
MONRE	Ministry of Natural Resources and Environment
MPI	Ministry of Planning and Investment
N2O	Nitrous Oxide
NAFIQAD	National Agro-Forestry-Fisheries Quality Assurance Department

NAMA	Nationally Appropriate Mitigation Action
NDC	Nationally Determined Contribution
NGO	Nongovernmental organization
PAD	Pangasius Aquaculture Dialogue
PoA	Program of Activities
QĐ-TTg	Decision of the prime minister
RAS	Recirculating Aquaculture Systems
RECP	Resource Efficient and Cleaner Production
SQF	Safe Quality Food
SUPA	Establishing a sustainable Pangasius supply chain in Vietnam
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
VASEP	Vietnam Association of Seafood Exporters and Producers
VietGAP	Good Aquaculture Practices in Vietnam
VMD	Vietnam Mekong Delta
VNCPC	Viet Nam National Cleaner Production Centre
WP	Work Package
WWF Vietnam	World Wildlife Fund for Nature in Vietnam

1. Background

The CGIAR Initiative on Low-Emission Food Systems, also known as Mitigate+, aims to reduce greenhouse gas (GHG) emissions from food systems and the predicted consequences of climate change on sustainable development and social equity. The initiative expects to help countries reduce emissions by 1.1 gigatons (6.5%) by 2030 by equipping local stakeholders in the Global South with the ability to make conscious GHG reduction decisions. The Initiative is structured into four technical research work packages (WP): (1) planning for low-emission food systems, (2) collecting data, evidence, and tools for low-emission food systems, (3) creating living labs for people, and (4) scaling up low-emission food systems. In Work Package 3 (WP3), the Living Lab for People (LL4P) approach will be used to engage local stakeholders in co-designing solutions to reduce GHG emissions in food systems. The approach will create a social innovation platform that facilitates interaction, testing, learning, and inclusive engagement among diverse food system stakeholders and researchers. The LL4P for low-emission food system development is defined as an inclusive and diverse space for people to co-design, test, demonstrate, and advance their socio-technical innovations and associated modes of governance within a facilitated organizational structure.

A strong focus on user involvement and co-creation distinguishes Living Labs (LLs) from other research and innovation methods. Stakeholders engage actively in the process of generating new ideas and technologies that suit their tastes and preferences, while CGIAR researchers collaborate in developing solutions that fit local needs. What separates LLs from other participatory methods is the focus on multi-stakeholder collaboration and innovation in a "real-world" context. The LL approach has been most applied to urban contexts for purposes of experimentation and testing of user-based information technologies, devices, applications, and media. More recently, LLs have been applied to agri-food systems with the aim to deliver benefits for participants and to improve environmental sustainability outcomes.

The literature of LLs in the agri-food system context is growing, with examples from both developed and developing countries. In Europe, the *Laboratoire d'Innovation Territorial Grandes Cultures en Auvergne* in France (Toffolini *et al.*, 2021), Agrolab in Spain, and the agri-food LL in Norway (Hvitsand *et al*., 2022) are examples of national programs, while AgriLink operates throughout Europe (Potters *et al.*, 2022). The LL concept has been gaining popularity in developing countries, some of which involve collaborations between institutions from both developed and developing countries in Africa (Mbatha & Musango, 2022; Ondiek & Moturi, 2019). A gap in the current LL literature is the lack of attention to questions of inclusion and power and how these social dynamics affect opportunities or constraints to innovation in the LLs. To ensure benefits are widely shared, there is a pressing need to study issues of power in the context of LL4Ps. The gaps in the literature suggest that more research on the implementation of LLs in the agri-food system context in developing countries is needed.

Figure 1. Map of Can Tho.

This report is part of a scoping study for LL sites in the Mekong Delta of Vietnam, focusing on aquatic food systems and identifying issues and potential intervention areas for WP3 ("creating living labs for people"). The specific focus of this study is the city- and provincial-level municipality of Can Tho, which has an area of 1,439 km^2 and a population of 1.28 million. Can Tho is located on the Hau River and is the largest city in the Mekong Delta (see Figure 1).

The purpose of the report is to compile, review, and analyze existing data, literature, and local knowledge about the LL4P site and relevant existing projects or programs in the site. In doing so, the development of the LL4P in Vietnam will build on existing efforts to develop low-emission food systems through the LL approach, which will rely on community-led innovation and the co-production of knowledge. The report is structured as follows: after this introductory section, section 2 provides a quick review of the LL4P approach, section 3 introduces our methodology, section 4 describes important characteristics of the aquatic food system in Can Tho Province, and section 5 evaluates the emission profile of the aquatic food system reviewed here.

2. An overview of the LL4P approach

At the most basic level, LLs are spaces where open innovation and co-creation occur by centering "users" (and their experiences) within everyday environments, commonly referred to as "real-world settings." There is tremendous diversity between the literature on and the practice of LLs. One of the most cited articles proposes four broad types of LLs: (1) utilizer-driven, or the organization or company employing an LL for the purposes of product innovation, (2) enabler-driven, which is typically an LL being used for the purposes of local governments for (the improvement of) public service delivery, (3) provider-driven, or universities/ research institutions with a specific innovation goal, and (4) user-driven, or a collective interest in innovation around a theme or common purpose (Leminen *et al*. 2012). There can certainly be overlap in these four typologies, as LLs can be part of a dynamic process that changes over time depending on the place, participants, or problem.

There are several key features that distinguish LLs from other research and innovation methods. First, LLs are characterized by a strong focus on user involvement and co-creation. Users are not just passive subjects of research, but are actively engaged in the design, development, and evaluation of new ideas and/or technologies. This enables researchers to gain a deeper understanding of user needs and preferences, and to develop solutions that are potentially more relevant and effective, depending on the context. Second, LLs are typically characterized by an open and collaborative approach to innovation. Researchers and stakeholders from different disciplines, sectors, and regions are invited to participate in the LL process, which fosters a diverse and multi-faceted perspective on the challenges and opportunities at hand. Third, LLs are typically conducted in so-called "real-world" settings, which allows researchers to test and validate new ideas in an ostensibly more realistic and ecologically valid context. This enables researchers to gain a better understanding of how new ideas might be adopted and used in the broader community, and to identify any unintended consequences or other effects.

Overall, the literature on LLs suggests that this research and innovation methodology has the potential to generate significant value for both researchers (Almirall *et al*, 2012; Dell'Era & Landoni 2014; Leminen *et al*., 2012) and users (Bridi *et al*. 2022; Habibipour, 2022; Soliman-Junior *et al*. 2022). By involving users in the co-creation and evaluation of new ideas, LLs can help researchers to better understand and address the needs and preferences of their target audience, and to develop solutions that are more relevant, feasible, and desirable. However, there are also several challenges and limitations to the LL approach, including the need to manage and coordinate the participation of multiple stakeholders (Leminen *et al*., 2015; Leminen & Westerlund 2012), the difficulty of scaling up successful innovations (Guzmán *et al*. 2013; Pfotenhauer *et al*. 2022; Plassnig *et al*. 2022), and the potential for bias and subjectivity in the evaluation process (Kareborn & Stahlbrost 2009; Nyström *et al*. 2014).

Existing reviews of LL literature point to the creation of the European Network of Living Labs in 2006 (ENoLL) as the first institutional commitment to design and implement LLs at a significant scale (Hossain *et al*., 2018; McLoughlin *et al*. 2018; Westerlund *et al*. 2018). Gamache *et al*. (2020) reviewed 763 articles that mention the term "Living-lab" and found significant Eurocentrism both in the origins and application of the concept. Of the articles they analyzed, 600 (or 78.6%) of the articles represented LLs in Europe (including England), 50 (or 7.0%) from the United States, and 118 (or 12.0%) from "other countries." The journal representation is also heavily skewed toward the disciplines of computer science, information science and communication technology, with only 15.9% relating to "green, sustainable science technology" in the most prolific years of publishing on LLs analyzed (2017–2018). LLs in practice and in literature also have an urban bias. There is extensive discussion on the challenges and opportunities of urban spaces for LLs, but few analyze the implications and implementation of LLs in rural or agrarian contexts (García-Llorente *et al*. 2019, reviewed below).

LLs in non-EU geographical contexts and those with differentiated objectives are now starting to fill gaps in the literature for how LLs are deployed outside of the "European movement," which is where the concept really gained momentum. This is precisely the aim of Galway *et al*. (2022), who argue that if LLs are going to be leveraged for social and ecological justice, then the concept needs to advance in four directions: (1) expand across a greater diversity of settings, (2) examine and analyze governance and power dynamics, (3) explore learning over time under co-creation, and (4) examine the role of academic institutions to impede or support the previous three directions. Indeed, these directions identified by Galway *et al*. (2022) are some of the cutting-edge topics currently being discussed in the LL literature that have advanced significantly beyond the "European movement."

The existing literature on LLs tends to focus extensively on the concepts, design, and implementation of LLs at a relatively small-scale. As other reviews point out, there is no agreed upon model. However, there is also no literature looking at the political economy of LLs and, more specifically, the political economy of developing countries for LL innovation. This is perhaps most important for the agri-food sector in the developing world, where poverty and hunger are most acute.

Literature of LLs in the agri-food sector is scant. Nevertheless, Potters *et al*. (2022) argue that LLs can contribute to agriculture and food systems policy in three ways: (1) through the products and outcomes the actors co-create, (2) through the dynamics and new relationships that can emerge (from LLs), and (3) by providing lessons and insights about the state of knowledge on agriculture and food systems. Within the existing LLs involved with food and agriculture, one of the first unsurprisingly emerged within the "European Movement." The AgriLink Living Labs were active from 2018 to 2021 in Italy, Latvia, Netherlands/Belgium, Norway, Romania, and Spain.

3. Characterization of the aquatic food system in Can Tho

3.1. Inputs

3.1.1. Chemicals

Chemical inputs are often used in aquaculture to manage water quality and pond sediment environments suitable for the aquaculture species being farmed. A recent study in Can Tho found 19 chemicals being used in stripped catfish culture. The chemicals included 10 types of water treatments and anti-parasite agents, seven types of antibiotics, and two diet supplements. In red tilapia culture in Can Tho, 18 types of chemicals were used, including antibiotics, water treatment, and anti-parasite groups. Generally, all chemicals used were approved by the Government of Vietnam, but most of antibiotics were listed for limited use by the the Ministry of Agriculture and Rural Development (Nguyen, 2018).

Chemicals are used intensively and extensively throughout every step of the aquaculture production process in Vietnam and other countries. Farmers often use liming compounds to improve water and sediment quality during pond preparation. Fertilizers are used to increase the natural productivity of ponds, while pesticides are mainly used to treat fungal and parasitic infections or to kill pests and predators of the cultured species. Disinfectants and antibiotics are used to maintain hygiene and to prevent and treat bacterial disease outbreaks. Feed additives, hormones, and probiotics are mixed with feed to ensure optimal diet quality and to improve the immunological status of the culture species. For pangasius in Can Tho and the Mekong Delta region, most farmers treat the seed with salt before stocking (Phan *et al.,* 2009). The use of local herbs for disease treatment and feed additives is a unique aspect that can only be found in Vietnamese and Chinese aquaculture (Phillips, 2000).

With regards to chemical quality and usage capacity, previous studies identify the low capacity of small-scale farmers to diagnose and treat diseases compared with larger scale grow-out farmers in the Mekong Delta, including Can Tho city. Large-scale farmers are also more likely to keep written records of management practices for individual ponds, to follow instructions of veterinarians or fish health technicians, and to resort to antimicrobial susceptibility testing of bacterial pathogens when applying chemicals (Ström *et al.,* 2019; Tran *et al.,* 2015). In contrast, for small-scale farmers in Can Tho, most red tilapia grow-out farmers (86%) used their own previous experience and/or label instructions to decide on the type and dosage of chemicals to be applied. Nearly all of the farmers did not keep any written records on chemicals applied. If farmers perceived that the antibiotic treatment had failed, the most common response was to change to another type of antibiotic. Some farmers also used antibiotics in the absence of clinical symptoms as a preventive measure (Nguyen, 2018; Ström *et al.,* 2019; Tran *et al.,* 2016).

3.1.2. Feed

The aquaculture feed manufacturing industry in the Mekong Delta is centered on Dong Thap and Can Tho, where the feed ingredient traders and feed mills are concentrated. Can Tho had the largest number of dried fish meal factories in the Delta, with the number of such factories slowly declining in An Giang and the other provinces in the Delta (Hasan *et al.,* 2019).

More than half of animal feeds in Vietnam are imported, especially high-quality protein sources. However, fish meal is mainly produced locally (Table 1). Fish meal is made from trash fish and raw catfish by-products from seafood processing factories.

There are two kinds of feed used for feeding pangasius in the Mekong Delta, namely manufactured pelleted feed and farm-made feed. The feed conversion ratio (FCR) of farm-made feed was higher and showed better net returns economically than pelleted feed. However, farm-made feed is gradually being replaced by manufactured pelleted feed or a combination of farm-made and manufactured pelleted feeds because of increased prices of feed ingredients for formulating farm-made feed. Besides, there were also increasing concerns over the impact of environmental pollution caused from farm-made feed (Nguyen, 2013).

3.1.3. Seed

Seed supply in Can Tho includes post-larval freshwater prawn (*Macrobrachium rosenbergii*) and pangasius fingerlings. A survey in mid-2003 suggested that a majority of freshwater prawn hatcheries in the Mekong Delta were located in Can Tho, which accounted for 45% of the hatcheries in the region (Nguyen *et al.,* 2006). Pangasius hatcheries, however, were located primarily in An Giang and Dong Thap provinces (Annex 1) (Hasan & Shipton, 2021). Can Tho is immediately adjacent to An Giang and Dong Thap provinces, allowing for ready access to fingerling supply.

3.1.4. Credit

Lem *et al.* (2004) conducted a survey on perception of access to credit financial institutions in the fisheries sector in Vietnam. They found that, in general, fish farmers in the southern region, including Can Tho, have easier access to credit than those in the north and central regions. Among state-owned financial institutions, most southern fish farmers found it very easy/easy to access credit from the Viet Nam Bank for Agriculture and Development (VBARD) (50% farmers), the Development Assistance Fund of Viet Nam (DAF) (42%), and the Social Policy Bank (SPB) (38%). Access to credit from other state-owned financial institutions and private banks was perceived to be more difficult. Compared with formal financial institutions, access to credit from informal sources, including moneylenders, relatives, friends, business partners, and wholesalers, were much easier, especially in the southern region (Lem *et al.,* 2004).

Table 1. Availability of feed ingredients (protein and carbohydrate) commonly used in pangasius.

Ingredients	Domestic production (tonnes)	Imported (tonnes)	Total (tonnes)
Protein sources			
Fishmeal	460 000	114 000	574 000
Meat & bone meal	Minimal	616 920	616 920
Distillers grains/corn gluten meal	Minimal	1 371 104	1 371 104
Soybean meal/oil cake	775 000	4 890 000	5 665 000
Peanut meal	Negligible	2 143	2 143
Copra meal	94 000	159 000	253 000
Canola oilseed	2 000	89 764	91 764
Palm kernel meal	Negligible	332 872	332 872
Sunflower meal	Negligible	16 728	16 728
Carbohydrate sources			
Rice bran	6 000 000	Negligible	6 000 000
Broken rice	1 500 000	Negligible	1 500 000
Cassava	2 000 000	Unknown	2 000 000
Wheat	None	2 900 000	2 900 000
Corn	5 280 000	7 700 000	12 980 000

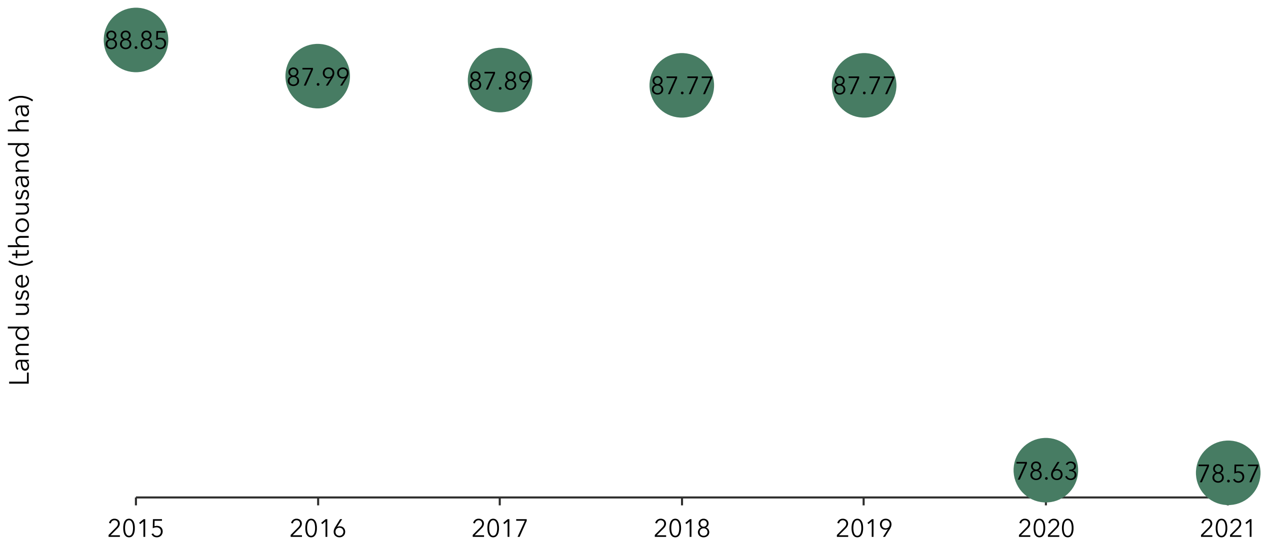
Source: *Hasan et al. (2019)*

Several reasons were mentioned to explain difficulties some aquaculture farmers faced in obtaining credit from financial institutions. In the study by Lem *et al*. (2004), the respondents gave the following: (1) fish farmers are too poor to provide collateral or to meet equity requirements, (2) in many cases, the amounts needed by them were too small to be of interest to banks, (3) in some cases, loan ceilings were considered too low compared with the requirements of the potential borrowers, (4) loan documentation requirements were complicated, (5) there were delays in processing loan applications and loan disbursements, (6) repayment periods were short, (7) there was a lack of knowledge about lending policies and procedures, (8) as well as a lack of mutual trust, (9) repayment schedules were inflexible and tight, while repayment intervals were short, and (10) the distance to the bank branch was too far, and interest rates too high (Lem et al., 2004).

3.2. Production and land use

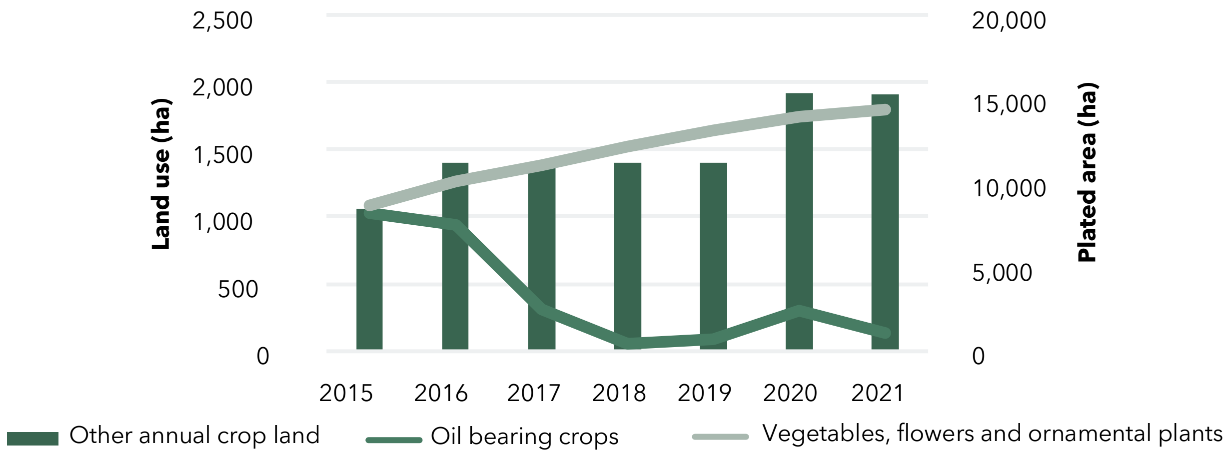
During 2015–2021, the agricultural landscape in Can Tho observed two main trends related to land use changes. First, marginally productive land dedicated to rice paddies decreased from 88,850.49 ha to 78,570.17 ha (Figure 2). Second, land devoted to "other annual" and perennial crops increased significantly, from 1,060.11 ha to 1,907.04 ha and from 23,241.63 ha to 30,722.46 ha, respectively (Figure 3 & Figure 4). Within the category of "other annual" crops, the area devoted to oil bearing crops dropped from 8,216 ha to 1,084 ha, while the planted areas of vegetables, flowers, and ornamental plants increased from 8,669 ha to 14,372 ha (Figure 3). For perennial crops, the planted areas of fruits, including mango and longan, expanded from 2,548 ha and 1,489 ha to 3,088 ha and 2,700 ha, respectively, while land used for coconut production declined from 2,308 ha to 1,517 ha (Figure 4).

Figure 2. Area of paddy land in Can Tho (2015–2021).



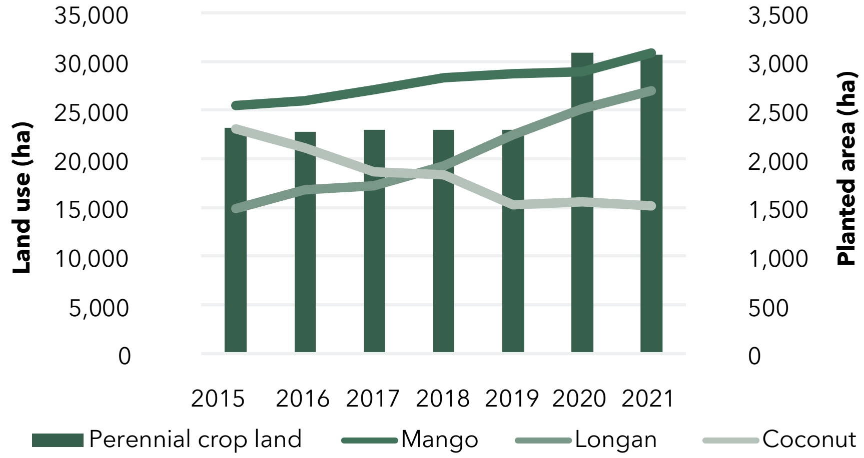
Source: *Vietnam's General Statistics Office (GSO) (2022)*

Figure 3. Areas of other annual crop land in Can Tho (ha) (2015–2021).



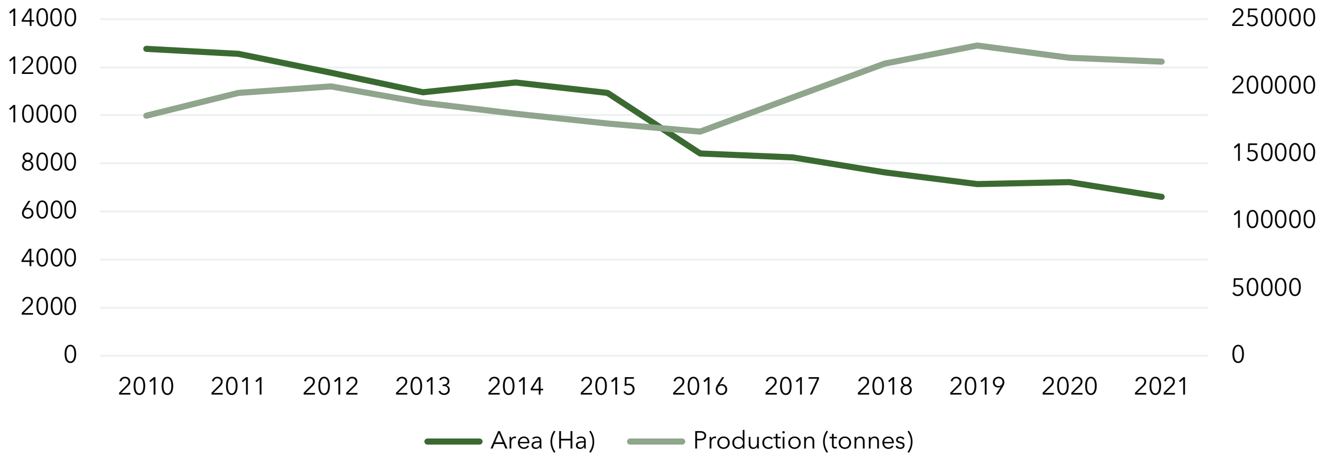
Source: *GSO (2022)*

Figure 4. Areas of perennial crop land in Can Tho (ha) (2015–2021).



Source: *GSO (2022)*

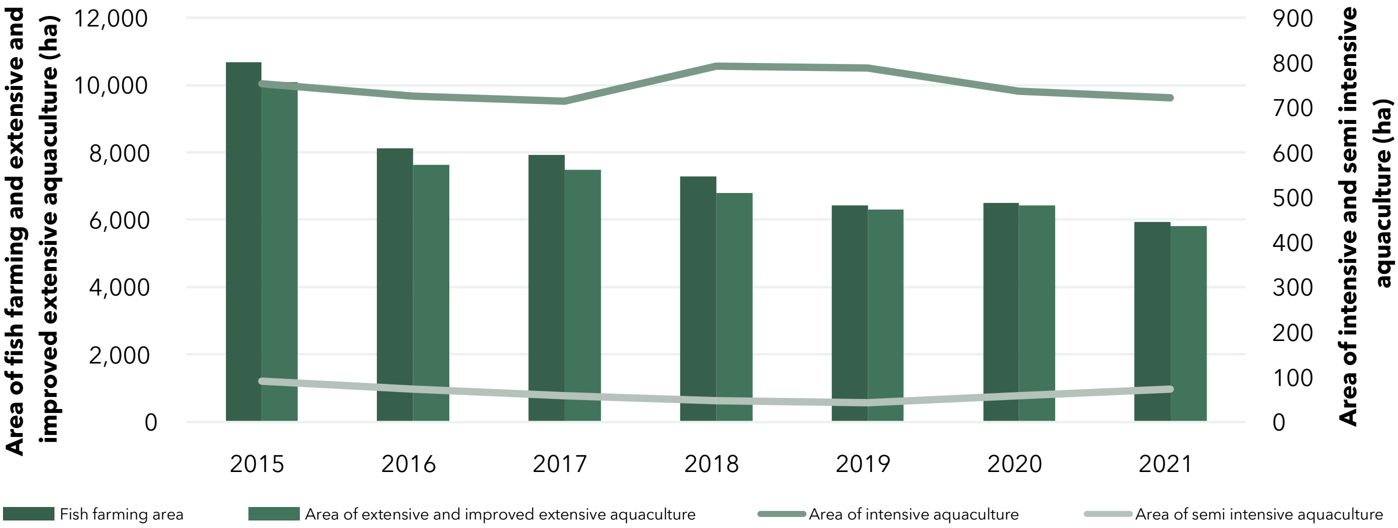
Figure 5. Aquaculture production and land area of Can Tho between 2010 and 2021.



Source: *GSO (2022)*

The total area for aquaculture in Can Tho declined from 2010 to 2021. As of 2010, the total aquaculture land in Can Tho was 12,764 ha and decreased to 6,605 ha by 2021 (Figure 5). This trend contrasted the national trend of increasing aquaculture land resulting from the government's Resolution 09/2000/NQ-CP, which allowed farmers to convert low-productivity saline rice fields into aquaculture ponds. The reduction of Can Tho's aquaculture area could be attributed to the reduction of unproductive area of extensive and improved extensive aquaculture by converting it into other land use for the urbanization and industrialization of the city. In contrast, area of intensive and semi-intensive aquaculture was hardly touched during the same period (Figure 6).

Figure 6. Fish farming area in Can Tho (2015–2021).

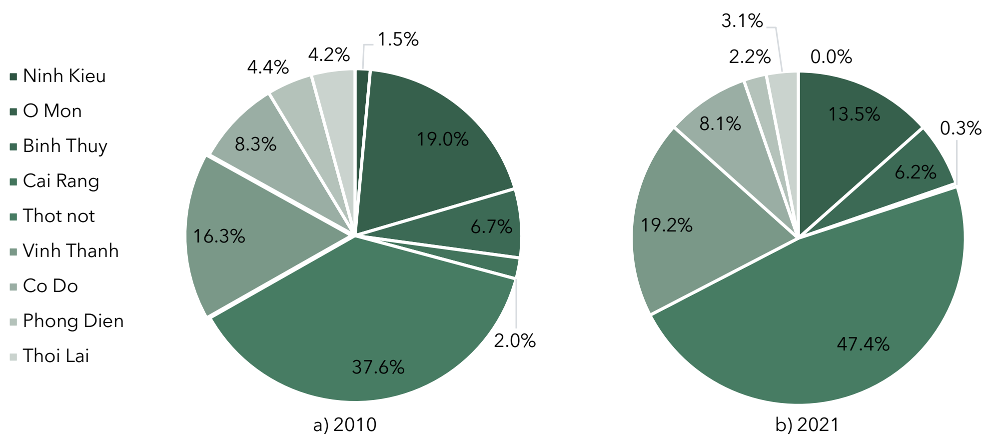


Source: *GSO (2022)*

In general, aquaculture production in Vietnam, and the Mekong Delta region more generally, has been on the rise since 1994. By the end of 2020, the region's aquaculture production had increased six-fold and contributed more than 50% of Vietnam's aquaculture production. However, the increase in aquaculture production observed in Can Tho was due to production intensification rather than the national trend of aquaculture area expansion. In fact, Can Tho's aquaculture production witnessed a sharp decline from 2012 to 2016, mostly due to a decrease in total aquaculture area. However, starting in 2017, and despite a decrease in area devoted to aquaculture, overall production rose significantly due to improved technology and intensity level.

Aquaculture in Can Tho is mainly located in O Mon, Thot Not, and Vinh Thanh districts. Thot Not produced 37.6% of Can Tho's aquaculture production in 2010, and its contribution increased to 47.4% in 2021. This district is located along the Hau River, next to the provinces of An Giang, Dong Thap, and Kien Giang. It has a favorable geographical position for aquaculture production in terms of water management and transportation. From 2016 to 2019, Thot Not district experienced a shift toward a more modern and industrial mode of production in both agriculture and aquaculture characterized by specialization in production and development of pangasius catfish (also known as striped catfish Pangasianodon hypophthalmus and hereafter referred to simply as "pangasius") production.

Figure 7. Percentage distribution of aquaculture production in Can Tho by district in 2010 and 2021.



Source: *GSO (2022)*

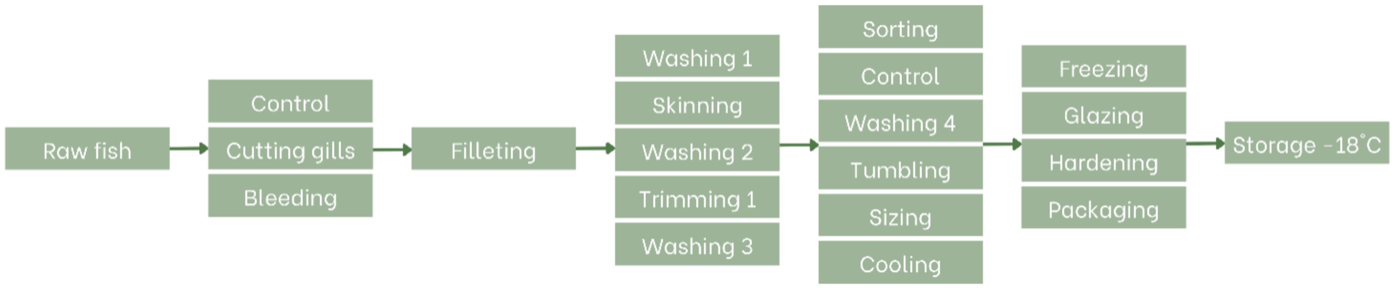
3.3. Storage and processing

Processing refers to mechanical or chemical operations performed on fish to transform or preserve them. Fish are processed in various ways and under different working environments (FAO, 2022). This section provides information on the storage and processing of pangasius in Can Tho and the VMD region.

3.3.1. Processing pangasius in Can Tho city

In the VMD region, the processing stage is mainly undertaken by export and processing companies (EPCs) (Le, 2019) following a process illustrated in Figure 8.

Figure 8. Schematic overview of Can Tho's Pangasius processing.



Source: *Tong et al. (2014)*

Live pangasius are transported from farms to the processing plants in specialized boats. These boats can carry tonnes of fish in large wells, which allow water exchange with the river. After being transported to the factory, pangasius are bled and filleted manually, then skinned mechanically. After washing, the subcutaneous fat and red muscle on the surface of the fillets are trimmed. The fillets are then washed in potable water before the second trimming step. Next, the fillets are washed manually in a water bath and sorted manually according to their color. After that, fillets are checked for parasites. Later, fillets are washed with chlorinated water. Then, the fillets are sorted manually based on their weight into four groups, placed into plastic bags, and cooled with flake ice. During the freezing process, the single fillets are frozen at -18°C in an individual quick freezer. Finally, the frozen products are packed, labeled, and stored at -18°C (Tong *et al.*, 2014). Frozen pangasius products include (1) whole pangasius, (2) pangasius steaks, (3) pangasius butterfly, (4) pangasius fillet (skin on), and (5) pangasius fillet (Okunogbe *et al.*, 2022).

3.3.2. Storage and processing in Can Tho city

In 2022, production costs and logistics costs were increasing due to external factors, but the export market for pangasius was extremely favorable. Processing is an important step in the that creates added-value in the production chain (Linh Thuy, 2022). Some enterprises have created high-value products such as collagen, fish surimi, refined fish oil, and gelatine (Nguyen, 2020a). Fresh pangasius skin products currently are priced at about 0.5 USD/kg, while collagen – a value-added product from pangasius skin materials – can reach 25–40 USD/kg. Realizing the role of deep processing, one of the leading enterprises in the industry, Nam Viet Joint Stock Company (Navico), has invested in a collagen processing factory from pangasius skin in Can Tho with a capacity of up to 800 tons of finished product every year. This strategic project helps the enterprise quickly transform its structure into high-value-added products (Linh Thuy, 2022).

Even though there are pioneering and successful businesses like Navico, the number of enterprises that have successfully transformed into high value-added products is relatively small. Most pangasius processing and exporting enterprises have limited interest in investing in value-added products because their technological sophistication is limited, investment costs for high value-added products is high, and pangasius fillets are easier to sell than other value-added products. In addition, managing value-added products is a managerial challenge (Okunogbe *et al.*, 2022).

In 2022, the seafood processing industry of Can Tho city had a problem with adequate supply of raw pangasius due to Covid-19 restriction regulations (Statistical Office of Can Tho, 2022). In fact, this problem has a certain chronic quality due to frequent fluctuations in the supply of raw materials, causing many processing factories to not operate at full capacity. Therefore, maintaining a concentrated and stable source of raw materials, ensuring good quality, and reducing input costs are priority concerns for the seafood processing industry (Phan, 2020).

3.3.3. Relationship between farmers and processing companies

The value chain of pangasius is a good proxy for the fisheries and aquaculture marketing chain of Can Tho (Hong Phuong, 2020). The value chain for pangasius in Vietnam's Mekong Delta (VMD), including Can Tho, includes primary producers, traders, wholesalers, EPCs, retailers, domestic consumers, and export markets (Le, 2019). In 2006, the product flow from fish farmers to EPCs was the primary channel for pangasius in the VMD region, with 81.3% of live pangasius being directly sold to EPCs (Nguyen and Tu, 2016). Of these, 86.2% was exported to foreign markets. In 2019, the proportion of live pangasius sold directly to EPCs rose to 96.6%, of which more than 91% was exported (Okunogbe *et al*., 2022). Therefore, in the context of the report, we limited our analysis to the value chain that includes farmers to EPCs to the export market.

Fish farmers

There is a strong linkage between fish farmers and EPCs. In 2010, nearly 97% of raw pangasius was sold to EPCs, while only 6% was sold through traders/wholesalers (Nguyen & Vo, 2014). For example, in 2019, most farmers sold their products right after harvesting to export and processing enterprises. Output is mainly distributed through the following two channels: 96.6% of fish is sold directly to EPCs, with the average farm-gate selling price in the year at 20,600 VND/kg; the remaining 3.4% is sold through traders, with an average farm-gate price of 20,200 VND/kg. The strong linkage between farmers and EPCs has helped both actors reduce transaction costs, as the product flows did not incur additional costs by going through the wholesalers/traders (Le, 2019).

However, despite the benefits, these linkages created many disadvantages for farmers. For example, many EPCs delayed and prolonged the payment time, sometimes up to several months without interest. Meanwhile, farmers had to pay interest to the bank, which could not be delayed as it would be difficult for farmers to access bank capital for subsequent production circles. This is a serious problem because farmers also need a substantially large amount of capital to produce the next crop of fish for harvest (Le, 2019).

Insufficient market information is one of the difficulties that fish farmers faced (Nguyen and Tu, 2016). A survey conducted in Can Tho by Le (2019) shows that up to 90% of farming households were completely unaware of the information on the production volume and selling price of raw pangasius farmed in other places. The lack of information could be attributed to the unreliable relationship between farming households and EPCs due to a lack of trust and transparency in the quality valuation of processors. This was especially the case when the valuation for fish products was done one-sidedly by the processors only (Dang *et al*., 2011).

Exporting and processing companies (EPCs)

a) Purchasing activities

In Can Tho, live pangasius is purchased directly at farm sites. The preferred purchasing size of pangasius ranges from 750 to 900 g. The purchasing and quality control of pangasius proceed as follows. First, farmers notify the EPCs of the harvesting time. Then, the collectors from the EPCs sample the live pangasius to assess their quality. The collectors evaluate the live fishes based on their color, size, disease, presence of antibiotics, and parasitic infection status (Le, 2019). A price is then quoted based on the assessment results. As of November 2022, the average farm-gate selling price of live pangasius was 29,500 VND/kg, with a top price of 30,000 VND/kg and a bottom price of 29,000 VND/kg (VASEP, 2022b).

b) Processing and consumption activities

As of 2019, more than 91% of processed pangasius in the Mekong Delta region was exported to foreign markets (Le, 2019). In the same year, Vietnam exported pangasius products to 138 markets with a focus on eight core markets, including China-Hong Kong, US, ASEAN, EU, UK, Mexico, Brazil, and Colombia, which accounted for 80.4% of the total export value. However, due to social distancing and the tightening of disease and quality control in response to the Covid-19 pandemic, EPCs have shifted their focus to other potential regions. In 2020 and 2021, the biggest export market for pangasius was the China–Hong Kong market, followed by US, EU, Brazil, and the Comprehensive and Progressive Agreement for Trans-Pacific Partnership. The export status of pangasius in 2022 was quite positive, as the export values to core markets substantially increased over the same period. In particular, the US became the number one pangasius export market of Vietnamese EPCs (Okunogbe *et al*., 2022).

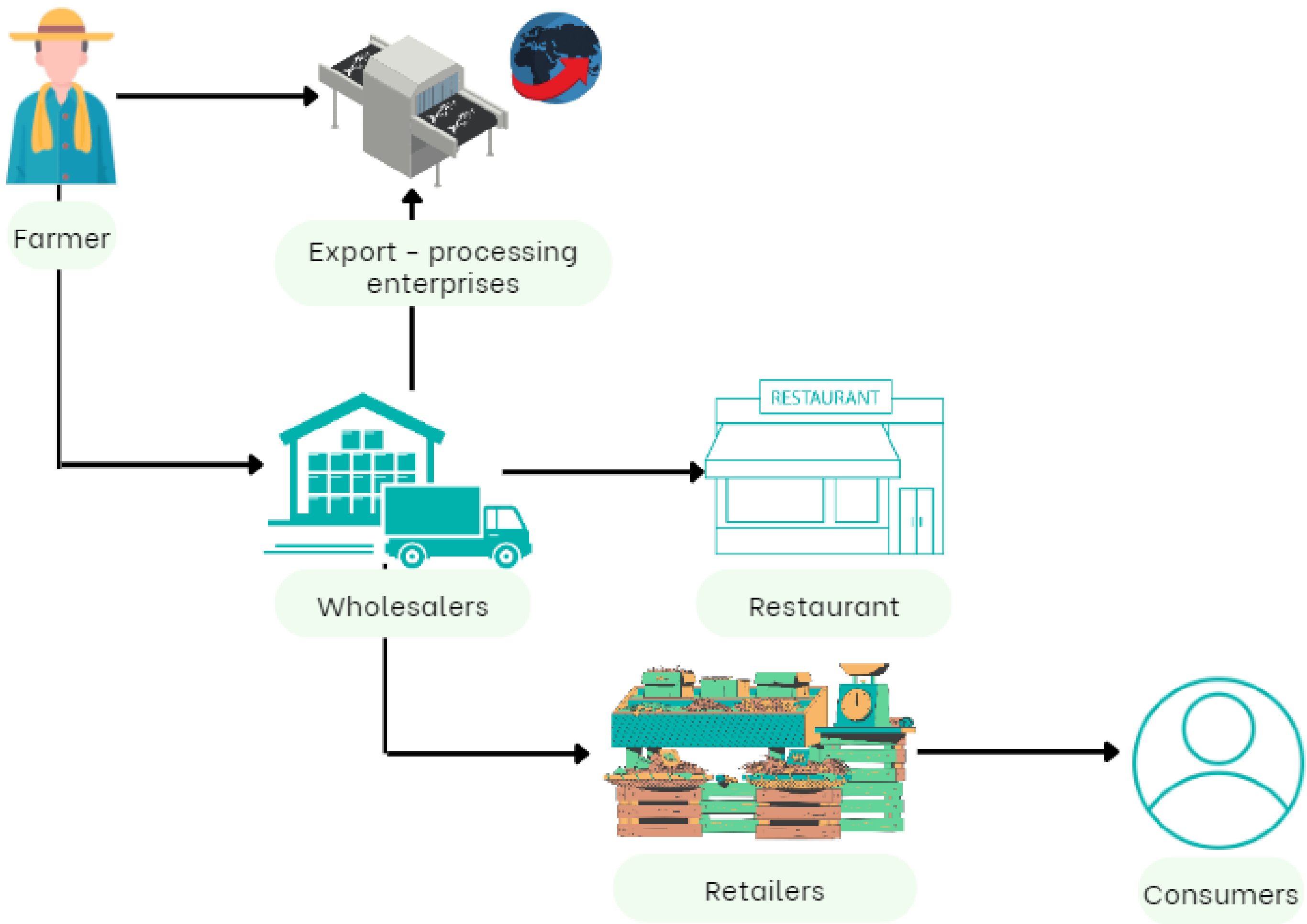
c) Vertical coordination

Since Vietnam's pangasius industry is export-oriented, with local markets almost nonexistent (Belton & Little, 2011), vertical coordination in the form of full integration and contract farming has become prevalent, especially in the Mekong Delta Region (Le, 2019; Trifković, 2014). The application of vertical integration into the pangasius marketing chain of Can Tho has brought many benefits to farmers and EPCs. These farms have substantially better farm performance in terms of yields and revenue per hectare than independent farmers in the catfish sector of the region (Trifković, 2016). Some other motivations for EPCs to implement vertical integration are to ensure a sufficient material supply as well as to create uniformity in product quality and safety standards for the marketing and export process.

3.4. Distribution

Located in the center of the Mekong Delta region, Can Tho is an ideal place to connect aquaculture production and distribution activities in the region. The aquaculture distribution chain in Can Tho is outlined in Figure 9. According to GSO (2021), Can Tho city was among the top 2 localities with the largest volume of freight traffic of goods transported by road in the region from 2010 to 2021. In resolution 78/NQ-CP, issued on June 18, 2022, the Vietnamese government set a goal that Can Tho city will become the logistics center of the region by 2030 (Vietnamese Government, 2022a). Can Tho will then have responsibility for linking, producing, processing, and selling agricultural products in the region. Developing Can Tho as the logistic center will help address disruptions in production and distribution by increasing cargo capacity and reducing logistical costs for agricultural and aquatic products for export (Nguyen Tuong & Thanh Tam, 2022).

Figure 9. Distribution diagram of the aquaculture value chain.



Source: *Luu (2020)*

In Can Tho's aquaculture value chain, wholesalers, retailers, aquaculture processing, and exporting enterprises play important roles in storing and preserving products for the end consumer. First, wholesalers are flexible and diversified in terms of the scale of operation. It is typical for wholesalers to handle larger volumes than retailers because of their ability to store and preserve aquaculture products (Nguyen, 2020b). Wholesalers often own or hire medium to large aquaculture equipment, such as trucks, shipping containers, and boats used to transport fish from farm to processing facilities or to urban markets. They also own or rent facilities for storing, preserving, or processing products, contributing to increasing the value of aquaculture (Tran *et al.*, 2021).

The COVID-19 pandemic negatively affected Vietnam's export trade of aquaculture products (FAO, 2022). Both processing and transportation were affected, leading to delays in the supply and distribution of aquaculture products in Can Tho. However, COVID-19 also had some positive impacts by increasing the use of e-commerce platforms to reach consumers. COVID-19 also stimulated distributors to review threats and opportunities, reassess priorities, and adjust distribution systems to become more optimal (Mai Hien, 2022; Nguyen & Nguyen, 2022; Thuy An, 2021).

3.5. Consumption

Global seafood consumption has increased rapidly over the past several decades. In 2019, the world consumed 158 million tons of seafood, which is more than five times higher than the 28 million tons consumed in 1961. The global growth rate of seafood consumption is 3%, while the population growth rate is 1.6%. In this remarkable growth, Asia alone accounted for 72% of total seafood consumption (FAO, 2022).

Consumers of seafood in Can Tho and the VMD region include domestic and international buyers. It is estimated that 10% of total shrimp production in the Mekong Delta is consumed domestically, with the rest exported to over 50 countries. The US, EU, and Japan are the most important international markets, accounting for 70–80% of total exported shrimp products annually (Nguyen & Chanagun, 2021). The primary export markets for pangasius are the US, China, and Hong Kong. The top 10 pangasius export companies in 2016 were Vinh Hoan, Bien Dong, Nam Song Hau, Hung Vuong, Nam Viet, IDI, Agrifish, Hung Ca, Go Dang, and Truong Giang. They collectively accounted for 55% of the total export revenue of pangasius (Nguyen & Chanagun, 2021). All of them are based in the Mekong Delta region. Bien Dong is based in Can Tho, while Nam Viet has its major factories in Can Tho.

As exports account for the lion's share of seafood production from Vietnam, one important factor influencing export activity is standards. The main international standards applicable to Vietnamese pangasius production are GlobalGAP, Best Aquaculture Practice (BAP), Pangasius Aquaculture Dialogue (PAD), Butler's Choice, Safe Quality Food 1000 (Safe Quality Food [SQF] 1000), and Naturland. Certificates from these six international standards certification groups are a form of market governance designed to control production processes and secure enterprises their commercial and institutional reputation. In addition, Vietnam also issued a national standard called VietGAP. In 2016, 60% of total catfish farming areas in the country pursued international certificates, while a large area was also eligible for VietGAP (Nguyen & Chanagun, 2021). Furthermore, technology is also vital in improving the aquaculture production and consumption value chain (Ganeshkumar *et al.*, 2021). Consumer beliefs and behaviors also play an important role in determining the adoption of technologies within the value chain that mitigate GHG in agricultural production (Del Grosso & Grant, 2014).

As mentioned, the domestic market is smaller than the international market for Vietnamese seafood. Due to rising incomes and internal migration from rural to urban areas, domestic seafood sales are projected to grow. Domestic consumers represent a different market for seafood producers. Vietnamese consumers buy and consume unpackaged fresh seafood products unlike consumers from developed countries, who buy and consume frozen seafood with formal packaging and information on product origins (Nguyen, 2017).

3.6. Regulators and extension agents

Market, trade, and consumer preferences drive the aquaculture market, with a clear need to create safe and high-quality goods (OCED, 2020). Data indicates that public trust in many governments is declining, while public perception of risk is rising (Condie *et al.*, 2022). As a result, there is a growing emphasis on strengthening enforcement of regulations over the aquaculture sector (OCED, 2020).

In Vietnam, the aquaculture management system is developed through a combination of top-down policies and regulations from the central to provincial government as well as bottom-up through the participation of local party committees.[7] The management and promulgation of regulations on the quality of aquaculture products is the responsibility of the Directorate of Fisheries under the Ministry of Agriculture and Rural Development (MARD) (Decision No. 27/2017/QĐ-TTg). In addition, the Agro-Forestry-Fisheries Quality Assurance Department (NAFIQAD) under MARD is the unit that controls the quality, safety, and hygiene of exported aquatic products (Decision No. 1120/QĐ-BNN-TCCB). It is important to note that enforcement of regulations also requires support from relevant associations and organizations (see Figure 10).

In general, Vietnam's fishing and aquaculture development policies have gradually been consistent and oriented toward sustainable development (Phan *et al.*, 2021). The Mekong Delta region stands out by making significant progress in sustainable development. In particular, Can Tho has been promoted by many policies and agricultural extension programs to be a strategic location of aquaculture in the region in recent years (Pham, 2020). In addition to the efforts of management agencies at all levels, activities related to agricultural extension agents have also been implemented by other institutions. Can Tho University is considered a research and development center for human resources in the aquaculture industry for the whole country (Hai Dang, 2022).

Collective fish farmers or farming organizations have more access to information from different extension channels than do fish farmers operating on their own (Nguyen & Tu, 2016). In 2005, Can Tho already had the largest network of cooperative farmers' organizations in the Mekong Delta region (Nguyen and Tran, 2005). Doing business with cooperatives helps farmers to strictly follow the technical process given by the enterprise (Picciotti, 2017). This is a necessary practical step in improving the ability to meet the requirements of food safety and hygiene, ensuring traceability to meet increasingly stringent requirements of import markets (Stazi & Jovine, 2022). Strict quality control explains why cooperative products have penetrated the US and EU markets. Regulators and extension agents have also been the subject of several government programs that have had a strong impact on aquatic food sector development in Can Tho (see Annex 2 and Annex 3).

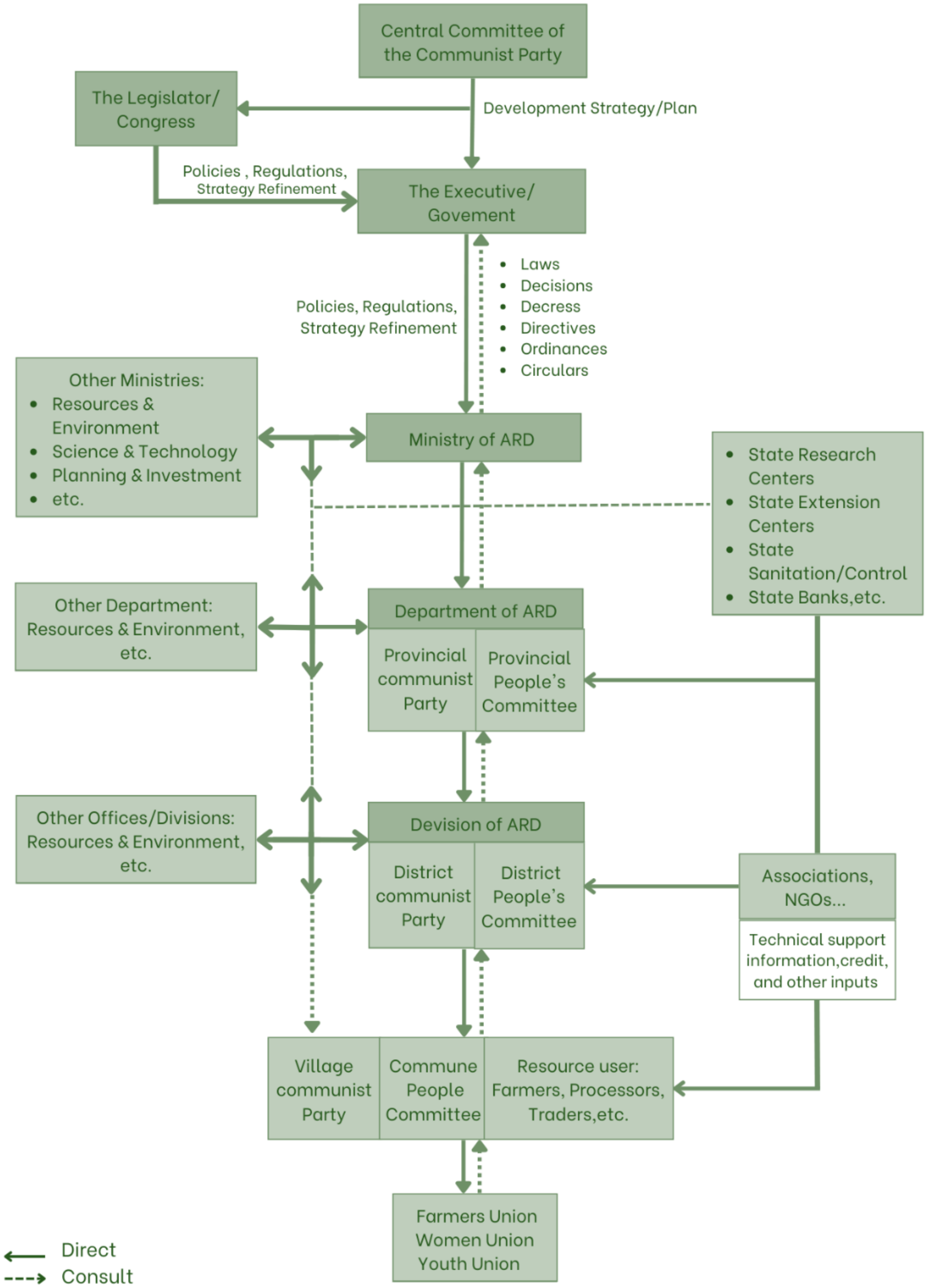
3.7. NGOs active in the aquatic food system

Numerous non-governmental organizations (NGOs)[8] from all over the world are actively interested in the development of aquaculture (Miller, 2021) and its impact on freshwater and marine ecosystems (Bostick, 2008). The cooperation between local and international NGOs has been beneficial when both actors complement each other's knowledge.

The establishment of aquaculture NGOs in Vietnam has had a significant effect on the nation's aquaculture sector. Vietnam has several major NGOs in the aquaculture industry, including the Vietnamese Association of Seafood Exporters and Producers (VASEP) and the International Collaborating Centre for Aquaculture and Fisheries Sustainability (ICAFIS). VASEP was created to represent and protect the interests of Vietnamese seafood exporters. It supplies processors and exporters with information and training on quality and safety requirements (Nguyen & Jolly, 2020). Additionally, VASEP gathers opinions from the private sector on shortcomings in the sector and proposes solutions to the government and the Ministry of Industry (VASEP, 2022). Regarding the ICAFIS, its mandate is to promote aquaculture and fisheries sustainability within Vietnam while also sharing experiences from Vietnam abroad. In addition, international NGOs in Vietnam such as the World Wildlife Fund for Nature (WWF) and Oxfam are also very active in the Vietnamese aquaculture industry. They facilitated development of international, science-based, voluntary standards for governing sustainable production in aquaculture (Pham *et al*., 2011). These organizations successfully linked with other organizations to implement projects to develop the aquaculture industry, especially in Can Tho.

Can Tho also has developed its aquaculture sector through programs/projects implemented by NGOs. VASEP has carried out activities since 2017 to overcome trade barriers affecting pangasius exports to the EU market. WWF Vietnam and the Viet Nam National Cleaner Production Centre (VNCPC) compiled guidelines on resource efficiency and cleaner production to improve pangasius processing (VNCPC, 2021). These local and international NGO activities affecting the aquaculture industry in Can Tho city are detailed in Annex 4.

Figure 10. The regulatory framework of the aquaculture system in Vietnam (2022 update).



Source: *Authors' summary based on Lai (2008); Veliu et al. (2009)*

3.8. Gender and social inclusion profile

3.8.1. Gender and social inclusion in the world

Although it is facing daunting ecological sustainability challenges, Vietnam's aquatic food sector still produces profits from the booming global seafood market. The sector underpins the livelihoods of millions of poor fishermen and their communities. The sector, particularly capture fisheries, is considered a "male-only" domain, apparently offering few opportunities to women in many cultures (Sze Choo *et al.*, 2008), as shown by an example from Vietnam (see Box 1). Some articles investigating complete fish supply chains show that the contributions of women and sometimes youth are substantial but largely invisible (Bosma *et al.*, 2019; Sze Choo *et al.*, 2008). Gender equality and women's empowerment are globally recognized priorities,[9] but it is clear that gender inequalities and barriers remain pervasive (Adam *et al.*, 2021).

Box 1: Women's positions in Vietnamese aquaculture

Previously, Vietnamese considered fish farming a male activity; women were less involved, and had little to no say in what techniques to use, or what to invest in (Voeten & Ottens, 1997). However, women in the North of the country have recently been involved in most stages of fish farming and are owning and leading hatcheries. In the South ,gendered norms around fisheries are different. Although women have not been allowed in hatcheries, they still have owned and led farms and processing companies (Bosma *et al.*, 2019). However, the role of women in planning and policymaking remains too low because their roles and opinions are generally not well accepted by men (Nguyen, 2012).

When participating in the sector, women make up a disproportionately large proportion of those engaging in the informal, lowest paid, least stable and less skilled segments of the workforce (FAO, 2022; Sze Choo *et al.*, 2008). They even often face gender-based restrictions that prevent them from fully exploring and benefiting from their roles in the field (FAO, 2022). For instance, in Bangladesh (Choudhury *et al.*, 2017) and other countries with similar social norms (Mukhopadhyay, 2016), economic opportunities for women are severely constrained by cultural, ethnical, or religious norms (Bosma *et al.*, 2019).

From another perspective of social inclusion, the economic benefits from fisheries and aquaculture are not shared equally. This is especially the case when considering the context of rapid population growth, looming food insecurity (Godfray *et al.*, 2010), and depletion of marine and freshwater fish stocks affecting food and nutrition security (Golden *et al.*, 2016; McIntyre *et al.*, 2016). Although aquaculture is a potential solution to cheaply and easily provide animal-source foods to poor and food-insecure people around the world (Kobayashi *et al.*, 2015), subpopulations that benefit from aquaculture profits may not be the same as those who are nutritionally vulnerable (Golden *et al.*, 2017). In fact, there are concerns that fish from aquaculture may not reach the poor (Golden *et al.*, 2017), as they may serve the market needs of those who are most able to pay (Cohen *et al.*, 2019).

In addition, the emergence of the COVID-19 pandemic has posed great challenges to livelihoods, employment, food security, and nutrition (FAO, 2022). Many individuals working in the aquatic food sector operate in the informal market with no social protection coverage. They are not registered in mandatory social security schemes, are paid less than the legal minimum wage, work without a written contract, or are self-employed. These individuals – including small-scale fishers, migrants, fish workers, ethnic minorities, crew members, harvesters, gleaners, and vendors – notably women, were the most affected by the pandemic (FAO, 2020, 2021). In addition, it was estimated that 3 billion people could not afford a healthy diet, with an additional 1 billion if the COVID-19 pandemic shock had reduced their income by one-third (FAO, 2020). Small-scale fisheries and aquaculture, small and medium-sized enterprises, women, and other vulnerable groups (e.g., informal and migrant workers) are increasingly marginalized and need to be properly protected by government programs and policies (FAO, 2022).

These pre-existing gender inequalities were exacerbated by the effects of COVID-19 (Atkins *et al.*, 2021). Women account for half the workforce when both primary and secondary fisheries and aquaculture sectors are considered (FAO, 2020). Nevertheless, they are under-recognized in the industry, despite their crucial role throughout the value chain and in household livelihoods and nutrition. Furthermore, the secondary sector has been hit particularly hard by the pandemic, and this is where most of the women work (FAO, 2020; Misk & Gee, 2020). Therefore, lockdowns in sectors that were hit the hardest have translated into greater declines in women's employment than in men's (FAO & WorldFish, 2021). However, it cannot be denied that women have also emerged as agents of change and leaders in the COVID-19 response (Misk & Gee, 2020).

3.8.2. Gender and social inclusion in Vietnam and Can Tho city

Lower Mekong Basin and Vietnam

Since 1993, Asia has become the world's main producer of aquatic products, mainly thanks to the development of aquaculture production. In 2020, Asian countries produced around 70% of global fish and aquaculture production (FAO, 2022). This region has strongly recognized the fact that women make very important contributions to fisheries. However, the lower status accorded to women in many Asian societies means that their contribution to fisheries is undervalued and unrecognized (Williams *et al.*, 2002).

In the socio-economic context of Asia, women in the Lower Mekong Basin participate in most fisheries activities. They play an essential role in processing, as well as in marketing fishery products (MRC, 2006). Some women participate directly in fishing activities with their family members in lakes, rivers, and streams. Fish selling is almost exclusively the domain of women (Williams *et al*., 2002). However, women's invaluable contribution is often overlooked and undocumented despite their pervasive involvement, such that women do not benefit from adequate working conditions, facilities, training, and access to information (Bosma *et al*., 2019). Moreover, the under-representation of women in decision-making exacerbates gender equality – not only in the community but also in the government (see Table 2). The participation of women at the policymaking level is extremely low in the Lower Mekong Basin. Three of the four countries – Cambodia, Lao PDR, and Vietnam – have lower than 10% representation of female officers in decision-making roles in fisheries ministries and departments.

Table 2. Female representation as decision-makers in fisheries ministries/departments in four countries of the Lower Mekong Basin.

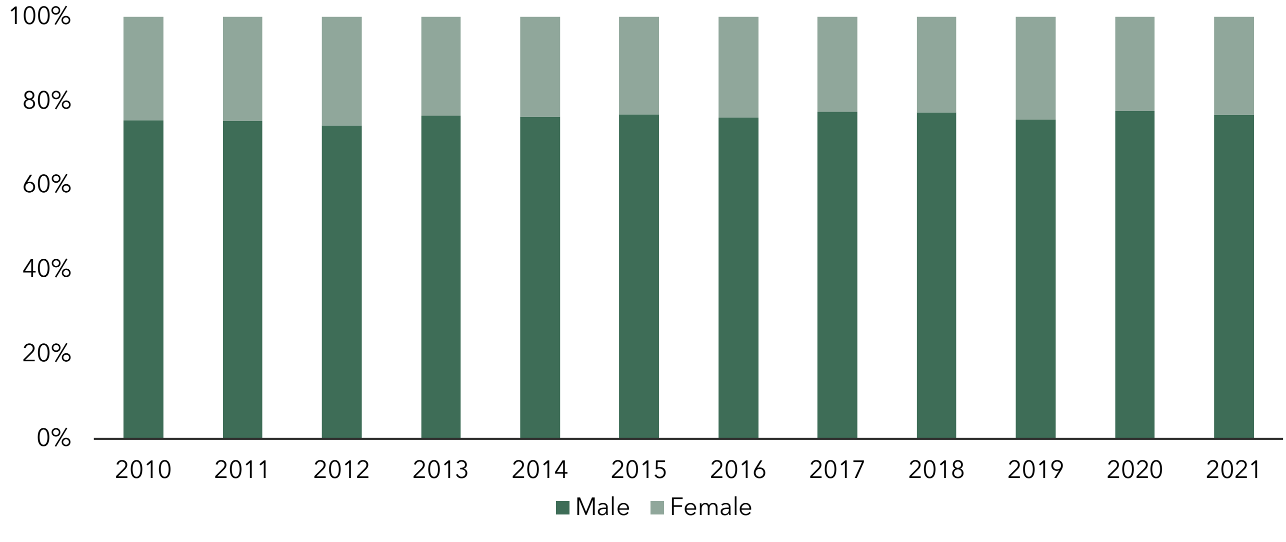
Ingredients	Total	Number of women	% female
Cambodia	134	8	6.0
Lao PDR	72	7	9.7
Thailand	257	75	29.2
Vietnam	144	12	8.0

Source: *MRC (2006)*

Note: *The definition of decision-making position differs from country to country: (i) in Cambodia, they are chief and vice-chief of the section or higher in the DoF and in Provincial Fisheries Offices, (ii) in Lao PDR, they were the deputy chief of section or higher in the DoLF, (iii) in Thailand, these were officials ranked 8-11, and (iv) in Vietnam, they were leaders of the MoFi and of its departments and 26 Provincial Fisheries Departments.*

In Vietnam, at the national and regional levels, there is no gender-disaggregated data on individuals involved in the aquaculture supply chain (Veliu *et al*., 2009). Figure 11 presents employment data in fishing and aquaculture in Vietnam disaggregated by gender; only 23% of those employed in this sector are female. The highest concentration of female employees is in the seafood processing subsector, with estimates ranging from 75% to 80%. Marketing and trading aquaculture fishery products from farms to final markets are done equally by men and women, with women playing a major role in the small-scale collection network (Veliu *et al*., 2009).

Figure 11. Sex-disaggregated data on employment in fishing and aquaculture in Vietnam 2010–2021.



Source: *ILO_Statistics on employment (2022)*

According to Bosma *et al*. (2019), some factors that affect gender equality in South, Southeast, and East Asia are (i) patriarchy, (ii) access to capital, and (iii) perceptions of women. Firstly, in terms of patriarchy, Vietnamese society is considered to have a weak patriarchial system compared to China. There are no or limited cultural prohibitions in Vietnam on women's mobility and distinctions between the public and private sectors (Kabeer, 1994). This weak patriarchy allows women to be flexible, and their role is negotiable. Men and women can work together (i.e., provide capital, labor, and expertise) to establish a joint business that will contribute to their diverse livelihoods portfolio regardless of who is the owner. At present, Vietnamese women may attend training courses organized by private companies when their husbands are not available, and their presence in public among men, in its own right, is not a limitation (Bosma *et al.*, 2019).

Nonetheless, evidence of the differences between gender in access to finance, land, and water is clear (Manji, 2010; Weeratunge-Starkloff & Pant, 2011). In Vietnam, farms are almost always registered by communes in the name of men representing households. Women in Vietnam are presented as lacking adequate networks that would allow them access to alternative credit sources that men have at their disposal. This difference might be a consequence of the gender difference in acquiring finance. Another reason is perhaps that women prefer to avoid the accompanying emotional burden of taking large loans (Veliu *et al.*, 2009). On paper, Vietnam's laws emphasize gender equality regarding access to property and land rights. In practice, however, women have been left behind. Compared to men, women are allocated smaller plots and less land overall; and women's names are often not included on land-use rights certificates (USAID, 2013). In fact, women in Vietnam typically only have access to land for aquaculture through co-ownership or renting (Nguyen *et al.*, 2015). Land-use changes may also lead to the exclusion of poor households in which women are the most vulnerable (Manji, 2010).

Third, the perception of task distribution between both genders is different compared to the actual tasks carried out by females. In Vietnam, women play an important role in marketing, feeding fish, and applying fertilizer in ponds (Kibria, 2004). Many people still perceive that aquaculture is a masculine activity despite the active role of women in aquaculture (Williams *et al.*, 2005). In male-headed households, men usually have greater say when making farm decisions, they own more of the assets, and retain more of the benefits (Brugere & Williams, 2017). In the processing industry, many executives may be aware or conscious of gender equality, but gender-biases remain and gender inequalities go unrecognized. For example, men are still better paid than women on the job due to dominant patriarchal viewpoints (Nuruzzaman *et al.*, 2014).

To achieve gender equality, many nations have developed gender action plans (GAPs) to support equal access of both genders to education, employment, and finance. Vietnam issued a policy on gender in 1997 and since then has encouraged various initiatives to mainstream gender in decision-making bodies, budgets, and development programs (Bosma *et al.*, 2019). Although all Vietnamese government bodies from the commune to the national level were required to formulate a GAP, no specific financial resources were allocated, legal frameworks for the implementation of GAPs were absent, and collaboration among government agencies was weak (Veliu *et al.*, 2009; Voeten & Ottens, 1997). A GAP can succeed only if there is (i) a budget, (ii) a committee, and (iii) collaboration between the women's union and the leaders of the provincial departments. Without collaboration between the women's union and other leaders, nothing will change (Bosma *et al.*, 2019).

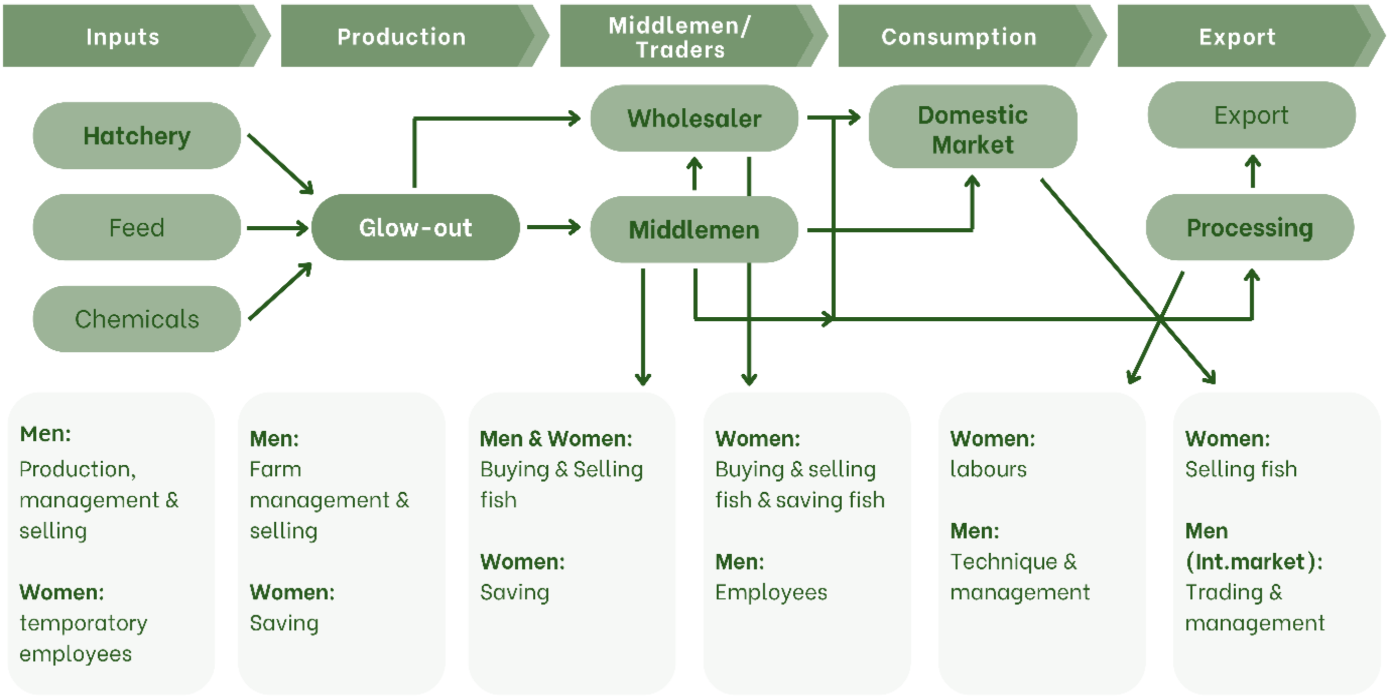
Gender and social inclusion in the Mekong Delta region and Can Tho city

The Mekong Delta region has the most diversified aquatic farming activities in Vietnam and great potential for increasing aquaculture production. A number of fish and shrimp species have been commercially produced in this region, such as pangasius and both brackish water and freshwater shrimp. Foremost within the aquaculture sector in Vietnam is pangasius production in the Mekong Delta. This in turn has spurred development of a large processing sector, which in 2007 supported the livelihoods of around 150,000 people, mostly rural women. Many other people were employed in other associated service sectors (Nguyen & Dang, 2010).

Men play a critical role at key stages through the aquatic food value chain in the region. For example, they obtain loans as the owners of the property because there are differences between gender in access to finance, land, and water. At the stage of harvest and price negotiation, men also dominate. In contrast, women are typically engaged in buying and selling in local markets, and working in export processing factories (see Figure 12). However, women are equally active as owners and managers in intermediary stages, and as workers in processing companies (Nguyen & Truong, 2014).

In Can Tho and the Mekong Delta region in general, new technologies and innovations in rice production have reduced labor burdens for female farmers compared to before, allowing them to engage in other economic and livelihood activities, including aquaculture. A study by Chi & Yamada (2002) in O Mon District, Can Tho, showed that technical training, meetings, oral knowledge dissemination, trust in the technician, and level of belief in a technology have all affected farmers' attitudes and behaviors in technology adoption and use. However, most women did not have access to technical training due to the gendered division of labor. Women are tasked with housekeeping and looking after children. As a result, they have limited time to attend technical training or other learning opportunities, resulting in low capacity. For example, in Thoi Thanh village, 30% of women attended integrated pest management (IPM) training in the previous two years (only 7–8 women in total). In Thoi Lai village, the percentage of women participating in technical training was only 10% (Truong & Yamada, 2002).

Figure 12. Role of both genders in the general value chain of aquaculture.



Source: *Nguyen and Truong (2014)*

4. The emission profile of the aquatic food system

Even though Can Tho has both freshwater fish and prawn farming, the literature on aquaculture emissions has only focused on pangasius production and processing. This is probably due to the relatively higher importance of the pangasius farming and processing sectors in Can Tho, in contrast to the relatively smaller freshwater prawn farming sector. Moreover, studies on GHG emissions from shrimp ponds in the Mekong Delta region were often conducted in coastal provinces and usually related to brackish water shrimp farming, which is not practiced in Can Tho (Alongi *et al.*, 1999; Järviö *et al.*, 2018; Jonell & Henriksson, 2015). Therefore, this section only focuses on reviewing the literature of emissions from pangasius farming in the region.

Previous studies (e.g., Henriksson *et al.,* 2014) attempted to capture the emission intensity of the pangasius value chain using a life cycle assessment approach. Their results may vary due to differences in methodology, including the feed composition used for the grow-out of pangasius, the FCR, the production scales, and the system boundaries (Table 3).

The first major difference in the studies summarized in Table 3 is that Henriksson *et al*. (2014) used wider system boundaries in their analysis, including emissions from cradle (egg, seed) to consumption in the EU (finished, frozen consumable product). The studies by Bosma *et al*. (2009) and Robb *et al*. (2017) only included analysis from hatchery to farm-gate.

These differences in data and methodology explain the great differences in findings reported in Table 3. Including EI analysis from farm-gate to consumers, wherever they live, is important to understanding the environmental impact of the pangasius production system.

The second major difference is that the studies use different feed compositions and FCRs. In general, Bosma et al. (2009) and Robb et al. (2017) compared different feed ratios to find the one with the least EI. However, Bosma et al. (2009) used catfish ratios with a higher proportion of high-EI material compared with the ones used in Robb et al. (2017). Moreover, the FCR in Bosma et al. (2009) was also higher than the value in Robb et al. (2017), which contributed to the higher EI in Bosma et al. (2009).

The third difference is that only Henriksson *et al.* (2014) compared three levels of catfish production scales and found that scales did not significantly affect the level of emission intensity in catfish farming.

4.1. Feed and other inputs

In general, production of feed and its raw materials is the largest single source of emissions from catfish farming in Vietnam. Feed production accounts for 52% of EI for Vietnamese pangasius. Emissions arising from feed depend on two variables: (1) the EI of the feed materials, and (2) the amount of feed used to produce live weight fish (the FCR) (Robb *et al.*, 2017).

Crop-derived ingredients and fishmeal were identified as the global warming potential (GWP)[1] hotspots in the feed production process. Crop-derived ingredients, especially rice by-products (bran, meal, broken rice), soybean meal, and wheat by-products (flour and bran) contributed the most to the GWP of feed production (41%); fishmeal contributed an additional 36% (Bosma *et al.*, 2011a; Nhu, 2017).

Table 3. Comparison of the emission intensity of pangasius systems among previous studies.

System	Emission intensity	Functional unit, kg CO_2e per kg of fishes	Methodological differences	Study
Pond	1.37	Live weight (LW) at farm-gate	From cradle to farm-gate; low emission feed ratio	Robb *et al.* (2017)
Pond (small)	8.02	Frozen fillet at import to EU	From cradle to export consumption in the EU	Henriksson *et al.*, (2014)
Pond (medium)	7.88	Frozen fillet at import to EU	From cradle to export consumption in the EU	Henriksson *et al.*, (2014)
Pond (large)	6.88	Frozen fillet at import to EU	From cradle to export consumption in the EU	Henriksson *et al.*, (2014)
Pond	8.93	LW at farm-gate	From cradle to farm-gate; average-emission feed ratio	Bosma *et al.*, (2009)
Pond	2.85	LW at farm-gate	From cradle to farm-gate; low-emission feed ratio	Bosma *et al.*, (2009)

Source: *Robb et al. (2017)*

[1] GWP and EI are exchangeable terms to describe the amount of kg of eq per kg of fishes.

Generally, pangasius rations, which are mostly commercial feed, have a low emission intensity due to having a high proportion of animal by-products and cassava (which tend to be high protein and low EI), and a low proportion of high-EI fish products. However, the low feed EI (0.49 kg CO_2e/kg dry matter) (Table 4) is offset by the higher FCR (1.52 kg dry feed fed/kg live weight gain), which makes catfish's feed material production EI comparable to the one of Nile tilapia but still lower than the one of Indian carps. The EI of feed materials is also affected by the land use change in countries of origin (the expansion of soybean in the US and Argentina). Moreover, a low survival rate could also increase the FCR and EI (Robb *et al.*, 2017).

There were contrasted arguments regarding the contribution of energy consumption by feed mills to GWP in Vietnam, mostly due to differences in assumption of energy sources. Nhu *et al.* (2016) argued that the inputs of milling processes contributed significantly to GWP (15%) due to the high consumption of electricity and fossil fuels. However, Robb *et al.* (2017) suggested that a significant proportion of the energy use in the feed mills comes from biomass (78.7% of total energy consumption), which is assumed to have zero net GHG emissions and lowers the overall EI of the feed (0.04 kg CO_2e/kg feed) (Table 4).

Studies show that catfish feed formulations have changed significantly over time. Robb *et al.* (2017) reported that farmers used a higher proportion of protein for the largest fish (22–26%) and small fish (28%), compared to the level reported in previous studies (18% and 26%, respectively) (Bosma *et al.*, 2011b; Bosma *et al.*, 2009). The protein used in the new formulation relied less on fishmeal (4–6%) compared to the past (8–26%), and more from animal by-product meals. The changes suggested a reduced proportion of high EI ingredients and an increased proportion of low EI materials in feed production.

Besides changes in feed formulation, Robb *et al.* (2017) reported an improvement in the FCR (1.69) compared with the level estimated by Bosma *et al.* (2011a) (R. Bosma et al., 2011) (1.86). However, the level of the estimated FCR was similar to a more recent study by Henriksson *et al.*, (2014, 1.64–1.7).

Emissions from feed also depend on the production technologies. There are two types of feed production technologies: extrusion and steam pelleting. The extrusion technology is more expensive and energy consuming than steam pelleting, but the resulting materials are more digestible. Some raw material need to be processed twice and thus more energy is used. Even though reworking feed material costs more energy, it reduces feed wasting because feed dust is not eaten by the fish and blows away. One hundred percent of surveyed pangasius farms in Vietnam use extruded pellets and average 1.55% of total feed production needs to be reworked (Robb *et al.*, 2017).

The emissions from fingerling production depend on the amounts of inputs, such as feed, electricity, and diesel, and the emissions factors of these inputs. Few studies focus on emission estimation in this area. Nhu *et al.* (2016) suggested that juvenile production contributed to a limited extent (lower 10%) to the environmental impact of the non-certified fish farms.

4.2. Fishing

Despite taking into account a low proportion of feed materials, fish meal contributed significantly to EI through trash fish fisheries. For 1,000 kg of Vietnamese fishmeal, burning diesel in fishing vessels contributed 54% of carbon dioxide, nitrogen oxides, and methane emissions in the catfish value chains. Moreover, the burning of diesel in transportation vessels by middlemen was the second-largest contributor (30%) to GWP. Other factors' contribution to GWP is negligible, including the burning of other fuel materials in power plants, refinery furnaces, production flares, rice farming, and transoceanic fuel transportation (Horsnell, 2018).

Table 4. Emission factors from various activities from pangasius systems, from post-fingerling to farm-gate.

	Unit	Emissions factors	Source
Feed material production			
Feed material production EI	(kg CO_2e/kg dry matter)	0.49	Robb *et al.* (2017)
Feed material production EI	(kg CO_2e/kg LW gain)	0.74	Robb *et al.* (2017)
Energy consumption and emissions in the feed mills	(kg CO_2e/kg feed)	0.04	Robb *et al.* (2017)
Emissions from transportation of feed from mill to farm	(kg CO_2e/tkm)	0.049	Robb *et al.* (2017)
Emissions from on-farm energy for three different energy sources			
Diesel	(kg CO_2e/MJ)	0.109	Robb *et al.* (2017)
Petrol	(kg CO_2e/MJ)	0.071	Robb *et al.* (2017)
Electricity	(kg CO_2e/MJ)	0.115	Robb *et al.* (2017)
Pond $N_2$0			
Pond (EF: 0.71%)	(g CO_2e/kg LW)	0.173	Robb *et al.* (2017)
Pond (EF: 1.8%)	(g CO_2e/kg LW)	0.438	Robb *et al.* (2017)
Small farms	(g CO_2e/kg LW)	0.347	Henriksson *et al.* (2014)
Large farms	(g CO_2e/kg LW)	0.353	Henriksson *et al.* (2014)
Cages in ponds	(g CO_2e/kg LW)	2.99	Henriksson *et al.* (2014)

Among the vessel classes, small trawlers had the highest GWP impact potential, with 1,700 kg of CO_2, which is equivalent per tonne of trash fish due to their high rate of diesel consumption, 35% higher than the second-largest emitter, large trawlers with 1,105 kg CO_2 eq, followed by falling gear vessels and surrounding gear vessels. However, due to their high contribution in the fish reduction industry, large trawlers had the greatest impact on GWP (Horsnell, 2018).

The reduction fishery in Vietnam suffers from a lack of efficiency where up to 35–48% of landings by trawl fisheries in Kien Giang are lost due to the number days the boat is at sea without ice before returning to port, which could spoil a large proportion of fish taken to the deck. As a result, the trash fish loss further increases the emission intensities of fishmeal. In general, the fuel required to catch 1 tonne of trash fish in Vietnam (333 liters/tonne) is much higher than the fuel intensity of Danish Sand eel (42 liters/tonne), Peruvian anchoveta (19 liters/tonne), and the global average for reduction fisheries (82 liters/tonne) (Horsnell, 2018).

4.3. Fish rearing

Emissions from rearing of fish in a pond usually come from on-farm energy use, primarily for pumping water, lighting, and powering vehicles. Therefore, this type of emission depends on the rates of energy consumption and the emissions factors for the energy mixture, including diesel, electricity, and petrol, that is used in the country (Robb *et al.,* 2017).

Other sources of on-farm emissions come from N_20 emissions from the water body on the fish farm. The emissions are the result of microbial nitrification and denitrification processes, which depend on the amount of nitrogen fertilizer not taken up by aquatic biomass, plus uneaten nitrogen in feed and excreted nitrogen. Therefore, the overuse of fertilizer and feeds could result in the stocking of nitrogen that can potentially turn into N_20 emissions. The processes of turning nitrogen into N_2O emissions are influenced by many parameters, including dissolved oxygen (DO) concentration, pH, temperature, etc. However, ponds could act as a net carbon sink if primary productivity is stimulated (Robb *et al.,* 2017).

The emissions from on-farm energy use are lower in Vietnam (24 g of CO_2e/kg of LW) compared with Indian carps and Nile tilapia due to a lower rate of energy consumption (209 MJ/tonne fish) and the lower emission factor for electricity (0.115 kg of CO_2e/MJ) (Table 4) (Robb *et al.*, 2017). The study also reported that on-farm energy use is lower than reported by previous research, suggesting that there might be an improvement in energy consumption (Robb *et al.*, 2017).

In Vietnam, intensive pangasius farms do not apply fertilizers because the number of fish is too large to benefit from the aquatic biomass and requires supplemental feeding. Uneaten feeds can be a source of nitrogen to produce N_2O emissions, but pangasius farms in Vietnam have a relatively high nutrient use efficiency, where on average 34% of the nitrogen consumed can be converted to fish biomass (Robb *et al.*, 2017).

Water exchange happens frequently in Vietnam catfish farms due to high stocking densities. This feature increases the energy consumption of on-farm activities. Some farms can offset this extra energy consumption by taking advantage of the tidal differences in river height to flood the ponds (Robb *et al.,* 2017). Other farms must pump water.

Generally, the global warming potential of Vietnamese catfish fillets to European consumers was lower for large-scale farms than for small- and medium-scale farms (Henriksson *et al.*, 2014, 2015). This is probably due to higher input use efficiency due to more careful monitoring and management observed at large-scale farms compared to smaller-scale farms, as reported in previous sections.

Integrated farming outperformed intensive pangasius farming for several environmental outcomes. Pangasius has been grown in integrated farms along with rice, fruits, vegetables, pigs, and poultry in O Mon district, Can Tho. Le *et al*. (2011) showed that the GWP of 5.2 kg of CO_2-eq per kg of fish in integrated farms was smaller than the GWP of 8.9 kg of CO_2-eq per kg in the intensive pangasius reported by Bosma *et al*. (2009). Kluts *et al*. (2012) found that the GWP contribution of rice-based high input fish culture is equal to less than 10% of the GWP contribution of intensive fish culture, while the GWP contribution of rice-based medium-input fish culture is even negative. This could be attributed to the lower use of external feeds by integrated farms, where pig manure is used for pond fertilization and crop residues are used to supplement the feed pellets. Therefore, the main source of GWP emissions from fish raised in integrated farms is CH_4 from diffusion processes in fish ponds instead of emissions from feed production (Le *et al*., 2011). Moreover, integrated systems use pond sediment to replace synthetic fertilizers used for crops, which reduces the emissions from fertilizer production.

Nhu *et al*. (2016) also found that the ASC certification scheme can positively influence the environmental impacts of pangasius farms, especially for emissions-related categories. The authors found that 66–93% of the ASC-certified farms outperformed farms that were not certified with respect to GWP. ASC-certified farms enjoyed several advantages, including lower FCR, lower nitrogenous discharges, and lower inclusion of fish-derived ingredients (fishmeal, fish oil, and trash fish).

4.4. Transportation and processing

Emissions arising from transporting feed materials and feed depend on distances from their place of production to the feed mills and from the feed mills to fish farms, as well as on modes of transportation for feeds (large trucks, small trucks/vans, domestic boat transportation, and international shipping). Boats are used mainly in the VMD, where many farms are not accessible by roads (Robb *et al*., 2017).

Emissions arising during the manufacture of packaging depends on the rates of packaging and the packaging emissions factors. Plastic packaging frequently is used by feed mills due to rough-handling and the damp conditions where the bags of feed will be stored before use. Bad handling and poor storage conditions at the farm can lead to wasted feed. Feed losses in transportation are low and controlled by the feed companies and farmers. Emissions resulting from post-farm processing are influenced by the rate of electricity use and the emission factor for electricity (Robb *et al.,* 2017).

In Vietnam, feed materials are greatly reliant on imports (soy from the US and Argentina) and, therefore, cost more fuel and produce more emissions. The country also has a long transportation distance from feed mills to fish farms. Much of this transportation is by boat (66 km by trucks and 130 km by boats), which has a lower EF per tonne km (0.049 kg CO_2e/tkm) than transportation by road (1.082 kg CO_2e/tkm). Two types of boats are used in Vietnam for feed transportation, where wooden boats have a lower capacity and speed and a higher level of fuel consumption than steel boats. In general, the emission intensity for transportation from feed mills to fish farms is 78 CO_2e/kg (Table 4) (Robb *et al.,* 2017).

5. Biophysical and ecological characteristics of Can Tho

Aquaculture is one of the main sources of income for people in the VMD and Can Tho; however, it also makes farmers vulnerable to the negative impacts of climate change (FAO, 2012b; Nguyen, 2014). Over the past few decades, climate change has had a significant impact on the VMD, such as frequent sea level rise, prolonged drought, erratic temperature changes, saltwater intrusion, and so on (Dang *et al.*, 2011; VASEP, 2021b). At the same time, climate change is one of the main causes that lead to disease outbreaks in the aquaculture industry in the VMD (De Silva & Doris, 2009), leading to a decline in aquaculture productivity (Dang *et al.*, 2011; Do & Ho, 2022). Environmental issues in the VMD and Can Tho include drought, salinity, floods, inundation, submergence, and rising sea levels that affect aquaculture.

5.1. Drought and salinity impacts on aquaculture

Two of the leading reasons for saltwater intrusion into the VMD are overexploiting groundwater and overexploiting sand in the riverbed to serve agricultural production (Open Development Vietnam, 2022). These activities cause the ground to subside and erode, resulting in decreasing elevation above sea level. As a result, during storm surges, combined with the incremental impact of sea level rise, tides and saltwater intrusion invade more quickly. Although Can Tho is located about 80 km from the rivermouth, the water level and salinity are still significantly influenced by the tides (Ozaki *et al.*, 2014). Tidal influence is increased during periods of drought when freshwater flow is reduced.

Drought conditions have the biggest impact on agriculture in the VMD. The dry season of 2019–2020 was considered the most severe drought in the history of the VMD, causing saline intrusion that affected 58,000 ha of rice, 6,650 ha of fruit trees, 1,241 ha of vegetables, and 8,715 ha of aquaculture in the VMD (Open Development Vietnam, 2022).

Saline intrusion has been a problem in some areas of Can Tho since 2015 (Le Hung & Thanh Bach, 2022). Salinity on the Hau River reached 2.05% in the dry season of 2016 and 3.5% in 2020. These levels exceeded the allowable level for drinking water and directly affected the aquaculture industry in Can Tho (MPI, 2022a). The reason is that most Can Tho farmers use river water for aquaculture (K.V, 2018). Most aquaculture products in Can Tho are freshwater species (pangasius, freshwater shrimp, snakehead fish) (MPI, 2022b).

Drought and saline intrusion often combine with high temperatures to adversely affect the growth and survival of local aquatic species (MONRE, 2003). According to Dang *et al.,* (2011) if the temperature increased 1°C (in the range of 27.5 to 29.5°C), shrimp yield could decrease by 90 kg/ha to 160kg/ha. Lower yields are caused in part by lower oxygen content in the ponds, which varies inversely with temperature (Luu *et al.*, 2019). Temperature increases also lead to water temperatures that exceed ideal conditions for shrimp production (Leigh *et al.*, 2020). In addition to temperature, the salinity in the water also significantly affects the growth process of shrimp. In the VMD, shrimp are often cultured in brackish water and experience physiological stress when optimal salinity levels are exceeded (Leigh *et al.*, 2017; Nguyen *et al.*, 2011). The result is that shrimp are physiologically stressed because they must spend more energy on osmotic management to maintain their osmotic balance rather than growing and feeding (Robertson, 2006). In addition, stress increases the risk of infection, which can result in mass mortality that can spread from one pond to another (Kautsky *et al.*, 2000; Tsai *et al.*, 1999). Acute hepatopancreatic necrosis and white spot syndrome are two of the diseases that can emerge as a result of high salinities (Leigh *et al.*, 2020). In 2011, saltwater intrusion and intense daytime heat caused shrimp to develop liver atrophy, which ultimately killed 80% of the VMD's farmed shrimp production (N. Hung, 2011). In 2015, 3,771 ha of shrimp farms suffered production losses due to saltwater intrusion in the VMD (DCC, 2017).

Similar to shrimp, pangasius is also a thermogenic animal, and high temperatures are an important cause of stress (Phan *et al.*, 2014). Salinity is an even more serious problem for pangasius production. Pangasius is a freshwater aquatic species that can tolerate salinity up to 5% (VASEP, 2021b). Since 2015, prolonged saline intrusion has affected the production of pangasius farming in Can Tho. As a result, in 2016, the pangasius farming area decreased 139 ha compared to 2015 (MARD, 2022). Through 2017–2019, the area under pangasius farming increased but was still lower than in 2015. By 2100, it is predicted that the area of pangasius farming in the VMD will decrease about 11% due to saline intrusion. This is caused by freshwater salinization of more than 5% during the dry season in several provinces in VMD (Tran & Nguyen, 2015).

5.2. Flooding, inundation, submergence and sea level rise impacts on aquaculture

The VMD is one of the most vulnerable deltas in the world to the effects of climate change and sea level rise (Tessler *et al.*, 2015). The VMD is the last downstream region of the Mekong Basin, which is affected by river control and environmental policies of upstream countries (Ozaki *et al.*, 2014). Many dams operating on the Mekong River control discharges and seasonal variations, thereby restricting fish migration (Osborne, 2009). Can Tho, surrounded by the Hau River, which is one of the largest tributaries of the Mekong River

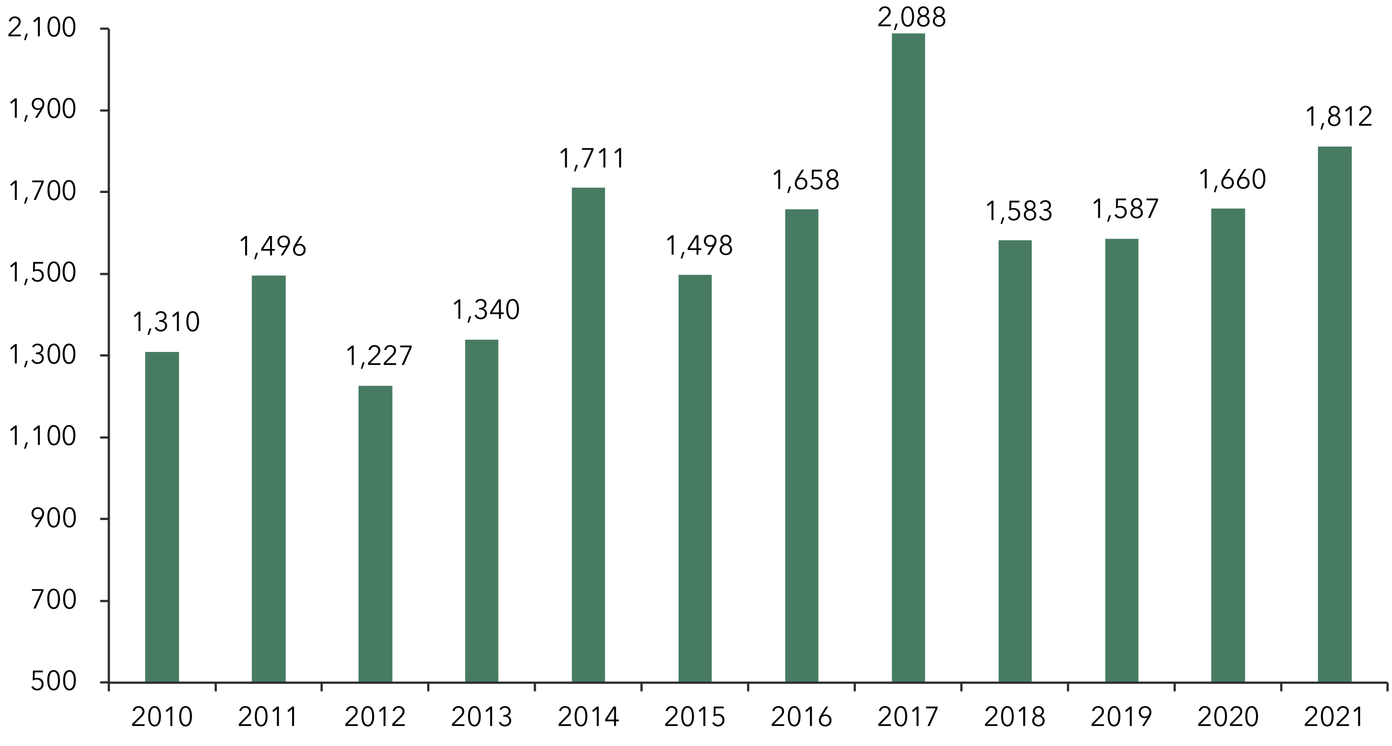
(Takagi *et al.*, 2014), is situated near the mouth of the river. This location serves as a transition area between the river and the sea, making it highly susceptible to upstream floods.

The hydroelectric dams of countries in the upstream Mekong River store water to serve electricity production, reducing the flow of water into the VMD and affecting riverine fisheries of that region (MPI, 2020). According to estimates by the Ministry of Planning and Investment of Vietnam (MPI), hydropower dams on the main tributary of the Mekong River can cause a reduction of up to 50% of the total catch in Vietnam. Disruption of the hydrological cycle along the Mekong River's course not only reduces fish stocks but threatens to have a huge impact on the region's biodiversity, including in the VMD. One study puts the risk of extinction at 10% of fish species in Vietnam (MPI, 2022b).

In addition, many studies predict that the flood risk in the VMD will be exacerbated by the impacts of high rainfall (Dang *et al.*, 2011; Takagi *et al.*, 2014). Similarly, an MPI (2022a) report also recorded the maximum daily rainfall and correspondingly increased the number of heavy rainy days in most of the sub-regions in Can Tho. From 1999 to 2008, the average total annual rainfall decreased. Between 2009 and 2019, however, rainfall increased sharply, at a rate of up to 50.48 mm/year (MPI, 2022a) (Figure 13). According to the MPI (2022a) report, climate change has caused a 1% increase in rainfall in Can Tho, resulting in higher occurrences of floods and landslides.

Heavy rainfall often carries with it high levels of contaminants that can accumulate and cause disease states in aquaculture ponds (Lebel *et al.,* 2018). In addition, inland aquaculture is highly vulnerable to flooding, as during floods it is very difficult to prevent fish from escaping from ponds and predatory fish from entering from the wild (Ahmed *et al.*, 2019). Submergence from the rainy season and tidal oceans has seriously affected pangasius farming in the VMD (Nguyen *et al.,* 2014). In 2011, more than 500 ha of fish ponds were lost to flooding in the VMD (VAWR, 2011). In recent years, there have been no massive floods in the VMD like the floods experienced in 2000 and 2011, and the frequency of major floods is decreasing, though annual precipitation is increasing (MPI, 2022b). Increased rainfall along with other causes of flooding in the VMD represent a constraint to the growth and expansion of aquaculture in the VMD in general and in Can Tho in particular.

Figure 13. Rainfall in a year at the Can Tho station – Hau River (mm).



Source: *Statistical Office of Can Tho (2022)*

6. Socioeconomic characteristics and institutional conditions of the site

6.1. Socioeconomic drivers of the aquatic system

Socioeconomic drivers shaping the aquatic food system of Can Tho include consumption demand drivers (increasing consumer income and population growth) and production supply drivers (trade policies and technological innovation).

6.1.1. Consumption demand drivers

Global population growth plays a vital role in influencing aquatic product demand. In 2021, the world's population was about 7.84 billion (World Bank, 2022) and is now forecasted to rise to approximately 9 billion by 2030 and 10 billion by 2050 (Gerland *et al.,* 2014). Vietnam and Can Tho also show a similar increasing trend in population over time, with an average annual growth rate of 1.0% and 0.4%, respectively. Rapid population growth is an important factor leading to increasing global food demand (Guillen *et al.,* 2019). Rising income is also a factor contributing to food demand, in general, and higher demand for seafood in particular (Vaughan, 2021).

How these two factors affect local seafood supply and demand in Can Tho is mediated by international trade and the ability of export markets to bid up seafood prices (FAO, 2012a). Countries like Vietnam have an incentive to expand their seafood trade, earning foreign exchange. Trade policies, including free trade agreements (FTAs) play a major role in facilitating trade expansion policies (Chan *et al.,* 2019; Mai Ca, 2022).

Increasing population and income, both locally and globally, will increase demand for seafood produced in Can Tho. Increasing market demand represents an opportunity for Can Tho's seafood producers, processors, and exporters to further develop the aquatic system.

6.1.2. Production supply drivers

Currently, participation in FTAs, such as the Comprehensive and Progressive Agreement for Trans-Pacific Partnership and the EU-Vietnam Free Trade Agreement, is an opportunity for Vietnam's seafood industry, especially Can Tho's seafood industry, to expand its market. However, with participation in international markets, Can Tho's seafood enterprises will have to meet conditions and comply with the rules of origin attached to each FTA. In particular, exporting to international markets will require tightening regulations related to food quality, safety, and hygiene, as well as environmental standards and labor conditions. Therefore, exporters in Vietnam must adopt a sustainability orientation, transparency, traceability, social responsibility, and environmental responsibility in the product production chain (Thanh Vu, 2022).

The application of new technologies to agricultural and aquaculture production has become an indispensable trend today. Scientific and technical advances in the field of aquaculture and seafood processing have helped the seafood industry improve productivity, and quality, meet requirements, and create more competitiveness and prestige for Vietnamese seafood products in the domestic market as well as for export (Thu Hoa, 2021). The promotion of the transfer and application of science and technology to production plays a crucial role in restructuring the seafood industry in the direction of increasing added value and sustainable development, ensuring economic integration, and keeping up with the trend of global science and technology development (Bao Chau, 2022). Currently, in the field of aquaculture, Can Tho is implementing many scientific and technical advances and new technologies to help farmers reduce costs, and loss rate, thereby improving the quality of life and production efficiency (Thanh Vu, 2022).

6.2. Institutional conditions

As previously mentioned in section 0, climate change has caused severe damage to aquaculture areas and production in the VMD and Can Tho city due to sea level rise, prolonged drought, erratic temperature changes, and saltwater intrusion. Therefore, on November 17, 2017, Resolution No.120/NQ-CP was promulgated by the Prime Minister of Vietnam on the sustainable development of the VMD to guide climate change adaptation. The two main goals of the resolution, to be achieved by 2050, are to (1) build a synchronous and modern socio-economic infrastructure network in the VMD, and (2) make the VMD become a well-developed region. The vision for 2100 is to create a sustainable, safe, and prosperous VMD, adapting to climate change (Vietnamese Government, 2017). This resolution is considered to be the guideline for the development of the VMD region as well as Can Tho (Le, 2021b).

In order to implement Resolution No.120, Can Tho has closely coordinated with other provinces in the VMD to carry out joint development activities to create cohesion between the provinces (Le, 2021a). To deal with climate change, Can Tho has carried out many activities, including raising awareness about climate change through training activities and organizing events (Tam Phuong, 2022). In addition, Can Tho will also strengthen its response to climate change through investment activities to enhance urban adaptability, including (i) investment in drainage, and domestic wastewater treatment, (ii) strengthening capacity to ensure clean water supply for people to use, especially in rural areas, and (iii) investment in an automatic monitoring system of saltwater and underground water sources to improve the efficiency of management and control of water quality to cope with saline intrusion (Le, 2021a). Resolution No.120 on the sustainable development of the VMD and adaptation to climate change has helped the VMD region's economy to have close regional connectivity, bringing highly effective production and economic development, orienting the VMD toward sustainable development (Bich Lien, 2021).

To promote development of the fishery sector, the Prime Minister of Vietnam signed the Decision No.339/QĐ-TTg on March 11, 2021: "Approving the strategy for development of Vietnam's fisheries by 2030 with a vision towards 2045" (Vietnamese Government, 2021b). The goal by 2045 is to develop fisheries into a modern commercial economic sector, sustainable, advanced management, science, and technology, and play an important role in the structure of the agricultural and marine economic sectors. Using the circular economy model to promote a green economy in the seafood value chain, the goal by 2030 is to investigate, evaluate, manage, and control sources of pollution and waste from the fisheries sector and end the use of toxic chemicals in aquaculture that pollute water and reduce biodiversity (T. Anh, 2022).

To carry out the development strategy, Can Tho's agricultural sector has been implementing many activities to support and create conditions to promote the application of scientific and technical advances to increase productivity. Can Tho actively encourages farmers and businesses to organize production in the direction of forming affiliate organizations to plan concentrated production areas. Can Tho also supports farmers who want to produce different species, including scads, snakeheads, perch, and eels (Bao Chau, 2022).

The Chairman of the People's Committee of Can Tho signed the Plan No.200/KH-UBND on September 22, 2022: "Action on green growth period of 2021 - 2030, vision 2050 in Can Tho city" (Vietnamese Government, 2022b). It sets out specific goals, including "Reducing the intensity of greenhouse gas emissions as a percentage of GDP." Accordingly, in 2030: "The intensity of greenhouse gas emissions per GRDP [Gross Regional Domestic Product] will decrease by at least 15% compared to 2014"; in 2050: "The intensity of greenhouse gas emissions per GRDP will decrease by at least 30% compared to 2014". In particular, the measures include (i) transforming the growth model toward greening economic sectors, (ii) applying the circular economy model through economical and efficient exploitation and use of natural resources and energy based on science and technology efficiency, (iii) applying digital technology and digital transformation, (iv) developing sustainable infrastructure to improve growth quality, and (v) promote competitive advantages and minimize negative impacts to the environment.

At the same time, greening lifestyles and promoting sustainable consumption include (i) building a green lifestyle combined with traditional beautiful lifestyles to create a high-quality life in harmony with nature, (ii) carrying out urbanization and building new rural areas to ensure green and sustainable growth goals, and (iii) creating a sustainable consumption culture in the context of integration with the world. Finally, it also includes accelerating the greening of the transition process on the principle of equality, inclusion, and resilience: (1) improving the quality of life and people's resilience to climate change, and (2i) ensuring equality and opportunities to promote capacity (Linh Le, 2022).

7. Existing knowledge, practices, or initiatives relevant to mitigation

As global warming and GHG emissions increase every day, timely responses toward reducing GHG emissions are needed more than ever. Therefore, it is necessary to have mitigation to reduce emissions and increase absorption (FAO, 2015; UNFCCC, 2022). In regards to fisheries and aquaculture activities all over the world, emissions contributions of this sector are smaller when compared with other sectors, but still significant during production operations, transportation, processing, and storage of fish (Cochrane *et al.*, 2009). The aquaculture industry needs to take emission reduction actions to ensure sustainability (Boyd *et al.*, 2020) through three main measures: (1) emission reduction, (2) emission avoidance or replacement, and (3) emission elimination (Ahmed & Solomon, 2016). In Vietnam, international mechanisms related to GHG reduction activities have also been promoted. There are 257 projects under the Clean Development Mechanism (CDM) and 13 CDM Programs of Activities (PoA) have been launched (Le & Nguyen, 2021). To reduce emissions and develop sustainably in aquaculture, numerous strategies, models, and initiatives have been introduced, including VietGAP, models that combine rice and shrimp, and technology application, among others.

7.1. Mitigation measures in the world

Regarding GHG emissions, methane (CH_4) and nitrous oxide (N_2O) are the gases that require special and serious mitigation measures because their contribution to global warming is much higher and they are more difficult to sequester after release into the atmosphere than CO_2 (Babakhani *et al.*, 2022). Some potential mitigation solutions for aquaculture systems are described below.

7.1.1. Adopting advanced scientific aquaculture practices

Integrated aquaculture systems are being considered as a new direction to help the aquaculture industry develop sustainably, with two outstanding farming systems, including integrated multi-trophic aquaculture (IMTA), aquaponics, and herbivorous fish polyculture.

IMTA is a production system that incorporates species of multiple trophic levels, each with different requirements such as finfish, shellfish, and seaweed (Cottrell *et al.*, 2021; Khanjani *et al.*, 2022). In this process, an integrated system is formed to minimize emissions from the aquaculture system (Raul *et al.*, 2020). Aquaponics is a hybrid system of aquaculture and hydroponics, where the fish farming unit and the growing unit remain in two separate systems or a combined system (Goddek *et al.*, 2019).

Herbivorous fish polyculture systems utilize selected herbivorous fish species to treat pond substrates during the feeding process because decomposing fish feed causes GHG emissions (Raul *et al.*, 2020). By selecting species that utilize different nutrient sources, producers are able to reduce the amount of fishmeal used, helping increase efficiency of feed use while reducing methane emissions from ponds and from fish meal production (Naylor *et al.*, 2000).

7.1.2. Using fish feed additives

The impact of feed additives can be reduced by up to 15% of GWP, for phosphorus emissions up to 30%, and for nitrogen emissions up to 50% (Spångberg *et al.*, 2014). The solution of using fish feed additives (Mao *et al.*, 2010), through the use of yucca extracts with other ingredients, showed a large reduction in emissions of CH_4 and NO_2 (Raul *et al.*, 2020). Therefore, feed manufacturers should pay more attention to the use of ingredients and additives in feed to contribute to the achievement of emission reduction targets in aquaculture (Boyd *et al.*, 2020).

7.1.3. Pond bottom sediment management

Methanogens and denitrifiers are more active due to hypoxia in pond sediments and negative redox potential. Using biochar to bind the bottom sediments prior to farming practices can significantly reduce GHG emissions (Raul *et al.*, 2020). The reduction in CH_4 emissions is also associated with a reduction in the proportion of methanogenic archaea compared to methanotrophic proteobacteria. This is because biochar application increases oxygen supply, which helps a group of aerobic methanotrophs. Through competition for nutrients between heterotrophic bacteria and nitrifying bacteria, it prevents the growth of nitrifying bacteria, thereby reducing N_2O emissions from aquaculture systems (Hu *et al.*, 2014)

7.1.4. About some other measures

Replacing higher emissions-intensive feed ingredients with lower emissions-intensive feed ingredients can reduce feed emissions. However, if the alternative feed ingredients have different nutritional properties, they can affect the physical performance of the fish, leading to an increase in FCR and nitrogen excretion, and thus an increase in gaseous emissions. Therefore, aquaculture households should choose quality raw materials and scientific feeding methods (MacLeod *et al.*, 2020).

Measures to reduce emissions in aquaculture require the participation of government agencies at the sectoral level and value chain participants at the site and enterprise level. Such coordination is also mentioned in the UNFCCC's

Bali Action plan (2007) Decision 1/CP.13, paragraph 1 (b) (ii) which states that developing countries in the context of sustainable development need to be supported and enabled by technology, finance, and capacity building, in a measurable, reportable, and verifiable manner. Therefore, smoothness of action is important in stakeholder groups, and the specific roles of these groups (see Table 5) are necessary for international cooperation in mitigation.

7.2. Mitigation measures in Vietnam and Can Tho

In recent years, emission reduction in aquaculture in Vietnam has received more attention due to export regulations (Do *et al.,* 2022), especially since the European markets have become strict on environmental issues (Do *et al.,* 2019). Can Tho has implemented measures such as Global GAP, ASC, SQF, and Best Management Practices (BMP). Some advanced emission reduction farming processes involving equipment, materials, breeds, feed formulas, and changes to practices in aquaculture systems have been researched and implemented (Thanh Vu, 2022). Table 6 sets out a set of effective measures to improve the productivity of pond aquaculture while addressing GHG emission problems (Nhu, 2017).

Table 5. Potential role of stakeholders in aquaculture sector emission reduction.

	Stakeholder groups	Roles
1	Ministries and agencies attached to the government	Leading the process and providing a legal and policy framework for allocating domestic public resources, applying for international funding, and providing an appropriate institutional structure (e.g., reporting and verification).
2	Farmers, fishermen, and their organizations	Prioritizing practices that are likely to promote implementation and provide feedback to raise awareness and lobby on behalf of farmers.
3	Agribusiness and other private business	Applying mitigation measures and providing feedback to help guide government investment in beneficial mitigation initiatives.
4	Civil society organizations	Monitoring accountability and raising awareness, providing feedback to government and the private sector, and lobbying for the public good.
5	Research and development institutes	Conducting research to identify practical mitigation options, improve methods of measuring and monitoring GHG emissions, analyzing policy needs and options, documenting economic and social benefits of reduction, and raising public awareness.
6	International organizations	Providing funding to support emission reduction efforts, promote the use of a measurement, create a reporting and verification system, and develop institutional capacity.

Source: *Wilkes et al. (2013); Wilkes A (2013)*

Table 6. Some mitigation measures for Vietnam in general and Can Tho in particular in aquaculture.

Measure	Mechanism	Mitigation	Source
Solution			
Nitrite (NO_2) monitoring	This solution is based on the principle of colorimetric using reagents. The device is compactly designed to be maneuverable during use. Measurement concentration: 0 ~ 5mg/L. Measurement accuracy meets the requirements of aquaculture.	Control and regulate feeding problems, avoid overfeeding causing emissions, especially N_2O and CO_2. Controlling NO_2 poison for pond treatment.	(Avnimelech, 1999; EFSA, 2008; Vu *et al.*, 2022)
Technology			
System for collecting and monitoring shrimp pond environmental parameters	Automatically collect and monitor parameters of temperature, salinity, pH, DO, NO_2, NH_3, H_2S; A shared system for 10 ponds. Data is put on the internet, can be viewed anytime, anywhere. Warning when threshold is exceeded.	Controlling oxygen concentration in ponds in a timely manner, continuously assessing DO concentration in ponds throughout the day as well as from the beginning to the end of the crop. Helps to reduce aquatic diseases by reducing risks due to lack of oxygen, high toxic gases in ponds; prompt response for water quality and pollution control.	(Lazur, 2007; Nguyen, Nguyen *et al.*, 2015; Simbeye *et al.*, 2014; Vu *et al.*, 2022)
Aerodynamic feeder incorporating IoT	Automatic cyclic feeding is set according to user needs. Capable of quantifying food at each feeding. Install and manage the machine remotely via smartphone.	Feed the fish in a completely automatic way while ensuring that there is no excess food.Fish form a habit of gathering around the food area, eating all the food, avoiding excess food, causing waste and environmental pollution.	(Luong *et al.*, 2020; NIPTEX, 2019; Vu *et al.*, 2022)
Water fan system using solar energy	Automatic energy regulation: maximum use of solar energy, when there is a shortage, additional grid electricity will be used. Capable of standalone or grid connection. Test power: 1.5 kW.	Instead of using diesel, people build equipment systems with solar panels to transfer to the battery. From there, it reduces the amount of oil consumed reducing emissions. Ensure oxygen supply for aquatic organisms, avoid suffocation leading to the death of farmed aquatic species due to power outage or out of fuel.	(Hai Minh, 2018; Vo *et al.*, 2021; Vu *et al.*, 2022)
Recirculating water filtration system in shrimp ponds	Water filtration systems can remove suspended organic solids in water. Has an automatic cleaning mechanism. Reduce TSS concentration in water (123.6 mg/L reduced to 40.2 mg/L). Estimated filtration flow is 1.5 m3/h (test model) and 150 m3/h (actual product).	Technology plays a role in cleaning water for shrimp farming, minimizing the generation of pathogens that occur in shrimp ponds. Cleaning ponds and toxic sediments (environment of methanogens).	(Nguyen *et al.*, 2019; Vu *et al.*, 2022)

Water treatment system for hatching eggs and hatching freshwater aquatic products with cold plasma	Application of cold plasma technology to kill bacteria and pathogens. Using input surface water after sand filtration. Output water meets QCVN 08-MT:2015/BTNMT	Plasma has the effect of inactivating bacteria and microorganisms, and the ability to oxidize organic and inorganic compounds present in water. Therefore, it is highly effective in sterilizing water as well as oxidizing organic compounds and inorganic substances, so it has great potential for applications in the field of domestic water treatment, aquaculture and water treatment. Cold plasma improves freshwater quality through reducing values of parameters such as BOD, COD, TSS, NH_3, Coliform, and increasing transparency helps to keep the breed healthy, avoid death in ponds, and limit emissions from aquaculture carcasses and harmful bacteria.	(de Sena, 2017; Sasi *et al.*, 2022; Vu *et al.*, 2022)
Model			
Combined hydroponics	Aquaculture tanks: Nutrient-rich wastewater (dissolved nitrogen, phosphorus) is a nutrient solution for plants. Hydroponics bed: biological filter (biofilter).	Water and nutrients accumulated from aquatic organisms, especially nitrogen, are derived from fish metabolism, as well as from uneaten food and organic detritus used as fertilizers for plants. This reduces the amount of N_2O as well as some of the waste of seafood released into the environment causing emissions.	(Monsees *et al.,* 2019; Vu *et al.*, 2022)
Incorporating Wetlands into Recirculating Aquaculture Systems (RAS)	The part of the wetland planted with plants plays the role of filtering clean water for the pond.At the same time, the RAS system will take wastewater from the pond to make fertilizer for plants.	Reduces potential environmental impacts such as eutrophication as well as water dependence, aids waste management (i.e., reduces waste volume in water) and enhances nutrient recycling. The total ammonia nitrogen removal treatment is biological oxidation to nitrate in a nitrification bioreactor that causes unassimilated nitrogen to be released into the water, mainly in the form of ammonia, which is toxic to fish.	(Vu *et al.*, 2022; Yogev & Gross, 2019)
Integrated agriculture-aquaculture	Animal manure and other farm waste are used to fertilize fish ponds. Pond bottom sludge is used to fertilize crops, and crop by-products are used to feed livestock and fish.	By utilizing the wastewater of different plant and animal species, the farming system reduces some of the emissions from the fish's uneaten food, taking advantage of the nutrients from the livestock. Therefore, pond fish farming also does not use chemicals in aquaculture that cause emissions.	(Le *et al.*, 2011; Le *et al.*, 2011; Vu *et al.*, 2022)

Source: *Compiled by authors*

8. Current/active policies/programs, initiatives, projects, or activities in the food system mitigation space in the region where our site is located

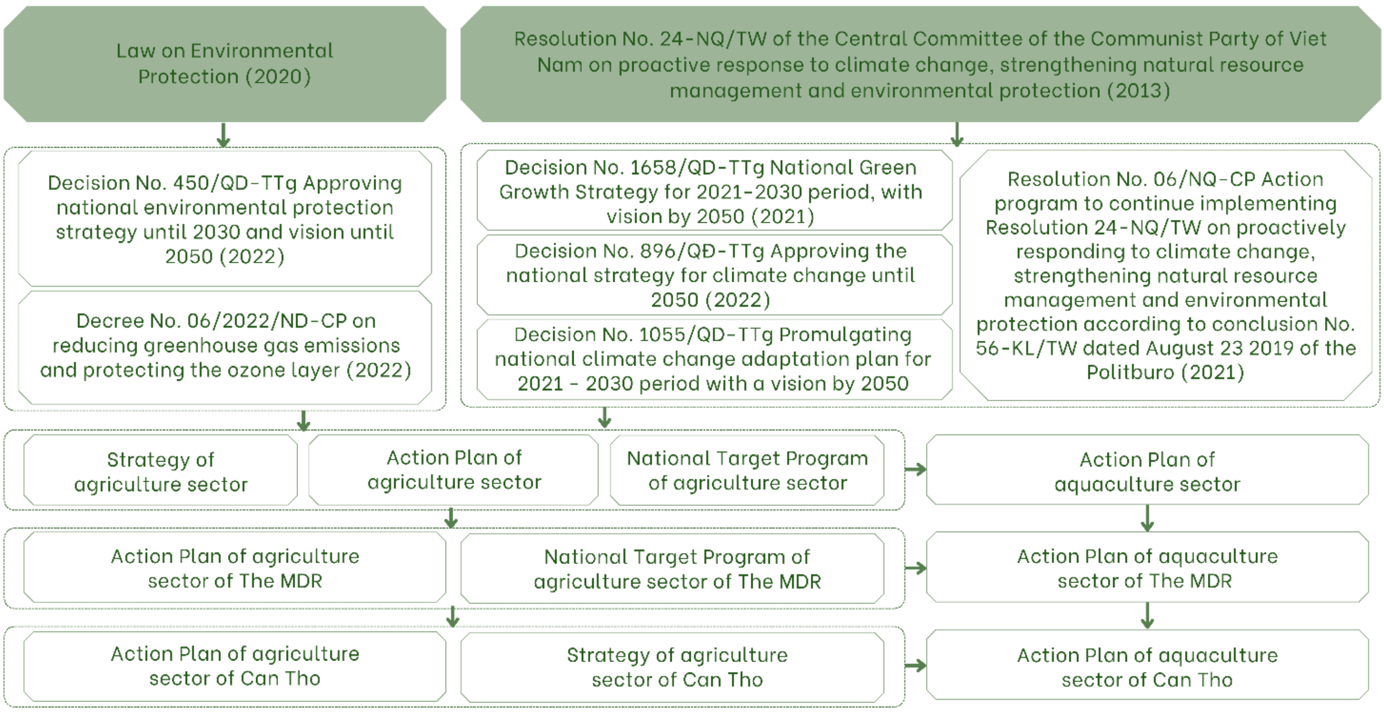
Vietnam has consistently demonstrated its responsibility and has taken the initiative to carry out international commitments on emission reduction (Vietnamese Government, 2022a). In particular, Vietnam signed and accepted the Paris Agreement in 2015, submitted its Intended Nationally Determined Contribution, and created a national plan for the Paris Agreement's implementation in 2016 (UNFCCC, 2015). Vietnam then promulgated the Law on Environmental Protection (2020), including the implementation of the country's Nationally Determined Contribution (NDC) and the Paris Agreement (Ngan, 2022). The chapter on climate change response has mandated responsibility for GHG emission reduction and adaptation to climate change. Vietnam and other countries pledged to reduce methane emissions by 30% from 2020 levels by 2030, and the national government joined the Global Coal to Clean Power Transition Statement to mobilize resources for climate change adaptation (Wang *et al.*, 2022). In the context of global commitments with COP27, Vietnam also has made a strong commitment to climate change. The target of a minimum GHG emission reduction in the period to 2030 is the total minimum GHG emission reduction in the period up to 2030 is 563.8 million tons of eq. Total energy consumption in agriculture, including forestry, is 129.8 million tons of eq.

8.1. Policy framework supporting the implementation of mitigation in Vietnam

8.1.1. Foundation of mitigation policies in Vietnam and Can Tho

From the Law on Environmental Protection (2020 update) and Resolution No. 24-NQ/TW of the Central Committee of the Communist Party of Vietnam on a proactive response to climate change, strengthening natural resource management and environmental protection (2013), the Vietnamese government has built foundational legal documents and systems to mitigate GHG emissions. From there, regulations on climate change and emission reduction have been integrated into strategies, action plans, and national target programs. Documents have been developed from agriculture to aquaculture, and from the national to provincial level (see Figure 14).

Figure 14. Current policies on mitigation in Vietnam and Can Tho.



Source: *Compiled by authors*

8.1.2. Policy framework supporting the implementation of mitigation in Vietnam and Can Tho

Ministries and sectors are continuing to develop and complete legal regulations, circulars, and technical guidelines to reduce GHG emissions under their management. The central and ministerial governments issued several important documents to achieve the goal of emission reduction and sustainable development in the aquaculture sector (see Annex 5).

In Can Tho, implementation plan No. 167/KH-UBND on the Sustainable Agriculture and Rural Development Strategy for 2021-2030, vision to 2050 was issued on August 8, 2022. According to the plan, Can Tho has proposed specific tasks related to the aquaculture system to achieve the objective of developing green and environmentally friendly agriculture, adapting to climate change, and reducing GHG emissions.

- First, develop the aquaculture industry in the direction of industrial concentration, modern technology through the application of improved technology, combined cage farming, concentrated pond culture, and crop rotation/intercropping. Priority is given to the development of the main specialized farming areas for pangasius products.
- Second, apply circulation technology toward recycling wastewater from aquaculture and seafood processing to reduce pressure on the environment.
- Third, complete the irrigation system to serve aquatic products in specialized farming areas. Next, organize effective linkages between large production enterprises and smallholder farmers through cooperative economic development, supporting the legitimate interests of producers.
- Finally, be proactive in providing essential inputs (seeds, feed, medicine) and processing seafood.

8.2. Programs, projects, or activities to mitigate GHG in the aquatic food system of Can Tho

There are four broad technological approaches to reducing the environmental impact of aquaculture: (1) breeding and genetics, (2) disease control, (3) nutrition and feeding, and (4) low-impact production systems. Within each of these approaches are many individual measures that could be used to reduce (or mitigate) GHG emissions (MacLeod *et al.*, 2020). Based on these four approaches, Vietnam has programs and projects to reduce emissions from the aquaculture industry. Regarding aquatic breeding, the Vinh Hoan Corporation[15] has implemented a project of vaccines for pangasius to improve the quality of breeding. In addition, the VietGAP application program in pangasius farming in Can Tho has contributed to effective disease control. Regarding nutrition and feeding, the project Nutrient Pond of Whiteleg Shrimp was implemented and effectively reduced emissions from aquaculture feed waste. Finally, United Nations Food and Agriculture Organization (FAO) projects, including Nationally Appropriate Mitigation Actions, innovative rice-fish farming, and climate resilient tilapia pond culture practices have resulted in new production methods with low environmental impact (see Table 7).

Table 7. Activities supporting the implementation of GHG reduction targets in Can Tho City.

	Program, initiatives, projects, or activities	Outcomes
1	Vaccine and welfare for pangasius	The Vinh Hoan Corporation promotes increasing the competence of fish health management, initiation of breeding programs, optimization of nutrition, and investments in new technologies. It signed a long-term strategic partnership agreement with PHARMAQ, a business of the leading global animal health company Zoetis. The collaboration involves large-scale vaccination of pangasius with ALPHA JECT Panga 2, a PHARMAQ vaccine that protects against disease caused by the bacteria *Edwardsiella Ictaluri* and *Aeromonas Hydrophila*. The large-scale adoption of vaccines is a major milestone for the Vietnamese pangasius industry. The use of efficacious vaccines can reduce or replace the use of antibiotics in the treatment of disease, ensure food safety, mitigate GHG emissions, and improve sustainability and profitability for fish farmers (VASEP, 2018b). According to Ms. Nguyen Ngo Vi Tam (CEO of Vinh Hoan), the vaccine coverage rate on the company's farming facilities is about 15%. Demand for antibiotics has decreased, while the growth rate and the rate of survival in vaccinated fish has increased (Fish Health Forum, 2021).
2	Program to support aquaculture establishments in Can Tho to apply Good Aquaculture Practices (VietGAP)	As for the aquaculture sector, VietGAP includes five sections with 68 required criteria to meet requirements for food safety, disease mitigation, ecological pollution, social accountability, and traceability of products. VietGAP focuses on sustainable development considering economics, society and the environment (Nabeshima *et al.,* 2015). Applying VietGAP standards helps Vietnam's pangasius production industry respond to requirements for fish disease control, mitigation, environment protection, social welfare, and traceability. As of June 2022, the total aquaculture production of Can Tho is estimated at 102,577 tons, in which the total area of aquaculture applying VietGAP standards reached 282.2 ha (Can Tho City People's Committee, 2022).
3	Nutrient Pond of White-leg Shrimp	This project is a part of a five-year research project led by Wageningen University in the Netherlands in partnership with WorldFish. In the VMD, repeated experiments over three years showed that a 20% reduction in feed intake, combined with low-cost supplemental carbohydrates, achieved yields similar to typical shrimp farming operations while reducing operating costs by about 10% (Elisabeth, 2016). Shrimp-farming industries are under increasing pressure to improve environmental sustainability. Since shrimp aquaculture involves the input of various feeds, fertilizers and chemicals that compromise water quality, the use of bio-indicators in conjunction with physicochemical variables may be beneficial (Fernandes *et al.,*2019). The project solved problems caused by aquaculture feed waste. These problems include greenhouse gas emissions, deterioration of the pond environment, and pathogenicity of aquatic species (Elisabeth, 2016).
4	Promote Scaling-up of Innovative Rice-fish Farming and Climate Resilient Tilapia Pond Culture Practices for Blue Growth	Rice-fish co-cultivation helps in the reduction of N_2O GHG emissions up to 9% compared to rice monoculture. However, methane emission from rice-fish farming is comparatively high, but by combining the appropriate fish with rice cultivation this drawback can be less harmful for the environment (Sathoria & Roy, 2022). FAO has supported innovative rice-fish farming and climate-resilient tilapia pond culture practices that are being disseminated among five regional initiative focus countries, including Vietnam. Two technical guidelines for practices of innovative rice-fish farming and climate-resilient tilapia pond culture based on the documentation of existing good practices were developed. The project promotes environmental benefits as a core element of farming practices. The beneficiaries of the project are highly motivated to continue and expand the innovative and climate-resilient practices introduced. In the long term, an overall enabling environment is the key for sustainability and scaling-up of farming practices promoted by the project (FAO, 2019).
5	Enhancing Nationally Appropriate Mitigation Actions Readiness: Building Capacity in Integrated Food and Energy Systems in Vietnam	Integrated systems increase carbon stocks, thereby contributing to climate change mitigation. When food and energy production is well balanced within an agro-ecosystem, many environmental risks can be substantially mitigated (Bogdanski, 2012). This FAO project has worked to improve national capacity for planning and implementing mitigation actions in agriculture. The project has increased the capacity of national policymakers to design and implement climate-smart agriculture policies, and national experts improved technical capacity in data collection on GHG emissions, modeling of emission factors, and identification of mitigation options in the agricultural sector (FAO, 2014).

Source: *Compiled by authors*

9. Discussion

9.1. Challenges and recommendations in developing and mitigating aquaculture in Can Tho

The current challenge for aquaculture regulators in Vietnam is to implement the right measures to enhance environmental sustainability without destroying social business initiatives (FAO, 2014). The application of too many standards and certifications in aquaculture in Vietnam also places great pressure on farmers (Belton *et al.*, 2011). To do well in the future, it is necessary to have specific short-term goals that are periodically adjusted following the socio-economic development of the world, Vietnam, and Can Tho in particular. In the long term, sustainable development and responsible production in aquaculture cannot be achieved without the full participation of all stakeholders in decision-making and regulation. This has led to efforts to empower farmers and their associations and move toward increasing self-regulation.

Although interest in emissions in aquatic systems has only emerged in recent years, several innovations have been vigorously adopted. In the future, Can Tho needs an accurate and comprehensive way of estimating GHG emissions from different aquaculture systems and different gas production mechanisms so that measures can be implemented for sustainable growth of the aquaculture sector. In addition, there is a need for international support in feed production technology, seed production technology, technical process of feed use and pond environment management, and synchronous "involvement" of many stakeholders in the country (government, businesses, farmers, etc.). Currently, aquaculture belongs to the agriculture-forestry-fisheries sector, but the technical regulation on industrial wastewater also is applied (QCVN 40:2011/BTNMT on industrial wastewater). Therefore, it is necessary to have separate measures and regulations on mitigation in the aquaculture industry through monitoring to understand the characteristics of the region. From there, appropriate solutions and technologies corresponding to different emission levels should be developed.

Regarding mitigation commitments, Vietnam has established a variety of guidelines, policies, strategies, initiatives, and plans to control climate change and maintain international commitments. However, there are still many limitations in policies and programs that Vietnam needs to improve. First, while many legal documents have mentioned mitigation, there is an overall lack of guiding documents to support state management, refining the legal system and legislation on GHG emission reduction. Second, stakeholder coordination in the planning and implementation of regional plans remains a goal rather than an accomplished achievement. Specifically for the aquaculture industry in Can Tho, current legal documents only set out the general goal of reducing GHG emissions, but there are limited specific regulations and guidelines for implementation. Third, production technology in Vietnam still laggs behind global standards. Continued research to develop modern technologies and practices for mitigation is required.

In addition, the core issue of climate change may not yet have been fully understood by farmers. In An Giang, Dong Thap, Vinh Long, Can Tho, Soc Trang, and Tra Vinh, more than 50% of the surveyed farmers were unaware of climate change adaptation measures (Nguyen, Truong, et al., 2015). Additional research needs to be conducted to ascertain if this level of awareness remains low. In the meantime, outreach efforts to improve the understanding of climate change adaptation methods for farmers in the VMD should be a priority. Local authorities in VMD provinces must initiate communication programs and training sessions to improve people's understanding of climate change and adaptation methods in aquaculture. Moreover, the government needs to cooperate with research institutes and universities in the field of agriculture in general and fisheries and, in particular, to conduct research and apply advanced and sustainable farming techniques and methods from other countries within the VMD.

Through the LL4P approach, some of the issues discussed above will be addressed within the local context in which the LL4P is established. By engaging in a process of co-creation with stakeholders in the food system, social and/or technical innovations that align with both government objectives for GHG mitigation and development goals can be identified and developed.

9.2. Steps toward achieving gender equality

On a global scale, more and more studies, reports, and programs on gender equality in fishing and aquaculture are being carried out. This suggests that this issue is receiving a lot of attention globally. However, Can Tho has not seen a lot of research on this subject, particularly in the past two decades. Therefore, it is necessary to perform additional studies on gender disparities not only in the VMD but also in Can Tho. To support the latter, instead of repetitive studies, the collection of national statistical data should be conducted to provide policymakers with appropriate gender-sensitive information (Veliu et al., 2009). Data currently available reveals major gaps on such topics as employment statistics (FAO, 2022).

Given the major role of women in artisanal and subsistence fisheries (WorldFish et al., 2018), increasing focus should be placed on the collection of gender-disaggregated data in informal, unpaid, subsistence activities. More information is needed on women's employment status in post-harvest activities of aggregation and distribution activities. Finally, the ancillary activities comprising the pre-harvest sector are not yet included in the fisheries and aquaculture employment statistics, as they are mostly informal. To recognize the role of the informal sector in supporting food security and ensuring women's financial empowerment, these activities should be taken into account and the collection of gender-disaggregated data would be prioritized (FAO, 2022).

The common prejudice of women not being considered as fishers/farmers (Deb *et al.*, 2015) leads to a gender bias in the conception and implementation of aquaculture development, and subsequently to the neglect of women. Therefore, it is important to increase the number of women in decision-making roles (Lentisco & Lee, 2014). Raising awareness and participation of both men and women, and engaging women as leaders, will help increase the contribution of women to this field.

Furthermore, the world in general, and Vietnam and Can Tho in particular, need to identify what is to be done and by whom to address systemic gendered inequities and barriers (see Table 8). Four pathways were developed to advance gender equality and women's empowerment in fish agri-food systems by the CGIAR Research Program on Fish Agri-Food Systems (FISH). These strategies include (1) gender-inclusive and gender-responsive innovations, (2) inclusive livelihoods and wealth generation, (3) inclusive governance, and (4) gender-transformative approaches to address underlying structural barriers (Adam *et al.,* 2021).

Table 8. What and who in gender equalities in fisheries and aquaculture.

Program, initiatives, projects, or activities	Outcomes
What is to be done	**Count women and make them visible** FAO's Committee on Fisheries can put gender equality on its agenda. Fisheries agencies can collect regular and accurate gender-specific catch-to-consumer employment data to track trends and progress.
	Increase funding to gender hundredfold Make greater investment in targeted gender projects, research, and educational outreach. The present quantum is so small and needs a hundredfold increase to achieve impact.
	Support women's empowerment Women can collaborate, assert their rights, and upgrade their capacity, if necessary with funding and support for education, advocacy, and legal resources. Men's and male-led organizations can become allies in enhancing women's autonomy over their lives and livelihoods.
	Collaborate on gender To make the invisible visible, gender equality must be a stated priority in policy, research, and programs, and expertise built into the key agencies along the catch-consumer pathway.
Who should do it	**Fisheries agencies** Regional, national, and international fisheries agencies and organizations, especially FAO, aquaculture and environment officers, managers, and policymakers.
	Funders Foundations, funding agencies, development assistance agencies.
	Researchers Fisheries and aquaculture researchers, gender researchers.
	Grassroots Women, community groups, fishing and aquaculture organizations and civil society.

Source: *GAFS (2018)*

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References

Adam, R., McDougall, C., Beveridge, M. C. M., & Marwaha, N. (2021). *Advancing gender equality and women's empowerment in fish agri-food systems: Four pathways*. Penang, Malaysia: CGIAR Research Program on Fish Agri-Food Systems: WorldFish.

Ahmed, N., Thompson, S., & Glaser, M. (2019). Global aquaculture productivity, environmental sustainability, and climate change adaptability. *Environmental management, 63*(2), 159–172.

Ahmed, O. O., & Solomon, O. O. (2016). Climate smart aquaculture: A sustainable approach to increasing fish production in the face of climate change in Nigeria. *International Journal of Aquaculture Fishery Sciences, 2*(1), 012–017.

Atkins, M., McDougall, C., & Cohen, P. J. (2021). *COVID-19 impacts on women fish processors and traders in sub-Saharan Africa: Insights and recommendations for building forward better*. Penang, Malaysia: CGIAR Research Program on Fish Agri-Food Systems:

Avnimelech, Y. (1999). Carbon/nitrogen ratio as a control element in aquaculture systems. *Aquaculture, 176*(3-4), 227-235.

Babakhani, P., Phenrat, T., Baalousha, M., Soratana, K., Peacock, C. L., Twining, B. S., & Hochella, M. F. (2022). Potential use of engineered nanoparticles in ocean fertilization for large-scale atmospheric carbon dioxide removal. *Journal Nature Nanotechnology*, 1–10.

Bao C. (2022). Can Tho promote the potential of aquaculture. *Communist Party of Vietnam online newspaper*. Retrieved from https://dangcongsan.vn/kinh-te/can-tho-phat-huy-tiem-nang-nuoi-trong-thuy-san-619150.html

Belton, B., Haque, M. M., & Little, D. C. (2011). Certifying catfish in Vietnam and Bangladesh: Who will make the grade and will it matter? *Food Policy, 36*(2), 289–299. doi:https://doi.org/10.1016/j.foodpol.2010.11.027

Belton, B., & Little, D. C. (2011). The social relations of catfish production in Vietnam. *Geoforum, 42*(5), 567–577.

Bich Lien. (2021). Resolution 120 brings the Viet Nam Mekong Delta to sustainable development. *Communist Party of Vietnam online newspaper*. Retrieved from https://rb.gy/4nkr7v

Bogdanski, A. (2012). Integrated food–energy systems for climate-smart agriculture. *Agriculture Food Security, 1*(1), 1–10.

Bosma, R., Pham, T. A., & Potting, J. (2011a). Life cycle assessment of intensive striped catfish farming in the Mekong Delta for screening hotspots as input to environmental policy and research agenda. *International Journal of Life Cycle Assessment, 16*, 903–915.

Bosma, R., Pham, T. A., & Potting, J. (2011b). Life cycle assessment of intensive striped catfish farming in the Mekong Delta for screening hotspots as input to environmental policy and research agenda. *International Journal of Life Cycle Assessment, 16*(9), 903–915. doi:10.1007/s11367-011-0324-4

Bosma, R. H., Hanh, C. T. T., & Potting, J. (2009). Environmental impact assessment in MEKONG Delta. (June), 58–58.

Bosma, R. H., Nguyen, T. D., Calumpang, L. M., & Carandang, S. A. (2019). Gender action plans in the aquaculture value chain: What's missing? *Reviews in Aquaculture, 11*(4), 1297–1307.

Bostick, K. (2008). NGO approaches to minimizing the impacts of aquaculture: A review. 227-249. doi: https://doi.org/10.1007/978-1-4020-6810-2_7

Boyd, C. E., D'Abramo, L. R., Glencross, B. D., Huyben, D. C., Juarez, L. M., Lockwood, G. S., . . . Tomasso Jr, J. R. (2020). Achieving sustainable aquaculture: Historical and current perspectives and future needs and challenges. *Journal of the World Aquaculture Society, 51*(3), 578–633.

Brugere, C., & Williams, M. (2017). Profile: Women in Aquaculture.

BTA. (2020). Can Tho University inaugurates 2 Japan-funded projects. *Communist party of Vietnam*. Retrieved from https://en.dangcongsan.vn/international-cooperation/can-tho-university-inaugurates-2-japan-funded-projects-601300.html

Can Tho City People's Committee. (2021). *Decision No. 26/KH-UBND*. Retrieved from https://chidanphapluat.vn/index.php?route=product/product&path=1731_1518_1738&product_id=458653

Can Tho City People's Committee. (2022). *Demand and proposed cooperation on science and technology of pangasius industry in Can Tho city*. Retrieved from https://tinyurl.com/ypv5f8vs

Can Tho Fisheries Sub-Department. (2020). *Report on environmental monitoring results for aquaculture in Can Tho city in the period 2016-2020*. Retrieved from https://tongcucthuysan.gov.vn/Portals/0/BC%20117.pdf

Chan, C. Y., Tran, N., Pethiyagoda, S., Crissman, C. C., Sulser, T. B., & Phillips, M. J. (2019). Prospects and challenges of fish for food security in Africa. *Global food security, 20*, 17–25.

Choudhury, A., McDougall, C., Rajaratnam, S., & Park, C. (2017). Women's empowerment in aquaculture: Two case studies from Bangladesh.

Cochrane, K., De Young, C., Soto, D., & Bahri, T. (2009). *Climate change implications for fisheries and aquaculture*. FAO Fisheries Aquaculture Technical Paper, 530, 212.

Cohen, P. J., Allison, E. H., Andrew, N. L., Cinner, J., Evans, L. S., Fabinyi, M., . . . Hughes, T. P. (2019). Securing a just space for small-scale fisheries in the blue economy. *Frontiers in Marine Science, 6*, 171.

Condie, C. M., Vince, J., & Alexander, K. A. (2022). Increasing polarisation in attitudes to aquaculture: Evidence from sequential government inquiries. *Marine Policy, 136*, 104867.

Cottrell, R. S., Metian, M., Froehlich, H. E., Blanchard, J. L., Sand Jacobsen, N., McIntyre, P. B., . . . Gephart, J. A. (2021). Time to rethink trophic levels in aquaculture policy. *Reviews in Aquaculture, 13*(3), 1583–1593.

CTU. (2015). Summary of Can Tho University upgrading project. Retrieved from https://caf.ctu.edu.vn/du-an-nang-cap-truong-dai-hoc-can-th0/225-du-an-nang-cap-truong-dai-hoc-can-tho.html

CTU. (2017). PANGAGEN: Towards a sustainable pangasius breeding, a selection approach. Retrieved from https://caf.ctu.edu.vn/en/58-international-projects-in-focus/110-pangagen.html?mid=87&limit-start=6

CTU. (2019). Demonstration Model of Advanced Aquaculture System for Education, Research and Development - DeMAASERD. Retrieved from https://caf.ctu.edu.vn/da-a-n-demaaserd/237-du-an-demaaserd-tom-sach.html

CTU. (2020). Faculty of Fisheries - Can Tho University started construction of high-tech shrimp farming at Vinh Chau brackish water aquaculture experimental farm. Retrieved from https://caf.ctu.edu.vn/hoat-dong-khoa-thuy-san/223-khoa-th-y-s-n-tru-ng-d-i-h-c-c-n-tho-kh-i-cong-xay-d-ng-cong-trinh-nuoi-tom-cong-ngh-cao-t-i-tr-i-th-c-nghi-m-th-y-s-n-nu-c-l-vinh-chau.html

Dang, K. N., Nguyen, H. T., & Nguyen, V. S. (2011). The impact of weather variability on rice and aquaculture production in the Mekong Delta. In *Environmental change and agricultural sustainability in the Mekong Delta* (pp. 437-451): Springer.

DARD. (2020). *Some difficulties in applying science and technology to agricultural production and orientation in the coming time*. Retrieved from https://snnptnt.quangnam.gov.vn/webcenter/portal/sonnvptnt/pages_tin-tuc/chi-tiet?dDocName=PORTAL187420&_afrLoop=2133735401552167&_afrWindowMode=2&Adf-Window-Id=j7onhu6kl&_afrFS=16&_afrMT=screen&_afrMFW=1322&_afrMFH=651&_afrMFDW=1366&_afrMFDH=768&_afrMFC=8&_afrMFCI=0&_afrMFM=0&_afrMFR=96&_afrMFG=0&_afrMFS=0&_afrMFO=0

DARD. (2022). *Signing cooperation agreement, linking production and consumption of agricultural, forestry and fishery products*. Retrieved from https://www.travinh.gov.vn/1444/38877/68079/671982/tin-noi-bat/ky-ket-hop-tac-lien-ket-san-xuat-tieu-thu-san-pham-nong-lam-thuy-san

DCC. (2017). Climate change adversely affects aquaculture. Retrieved from http://www.dcc.gov.vn/tin-tuc/3264/BDKH-anh-huong-xau-den-nuoi-tr%C3%B4ng-thuy-san.html

de Sena, A. P. S. (2017). NEREU Project: Construction of a plasma reactor for reform of greenhouse gases for treatment of wastewater of the marine darms. In *Desalination*: IntechOpen.

Deb, A. K., Haque, C. E., & Thompson, S. (2015). 'Man can't give birth, woman can't fish': Gender dynamics in the small-scale fisheries of Bangladesh. *Gender, Place Culture, 22*(3), 305–324.

Del Grosso, S. J., & Grant, D. W. (2014). Reducing agricultural GHG emissions: Role of biotechnology, organic systems and consumer behavior. *Carbon Management, 2*(5), 505–508. doi:10.4155/cmt.11.47

Dieu Tam. (2022). *Can Tho: Aquaculture production is estimated at 102,577 tons in the first 6 months.* Vietnamese seafood. Retrieved from https://thuysanvietnam.com.vn/can-tho-san-luong-nuoi-trong-thuy-san-uoc-dat-102-577-tan-trong-6-thang-dau-nam/

Do, B., Nguyen, U., D'Souza, C., Hoang, T. H., Le, Q. H., & Nguyen, N. (2022). Implementing eco-friendly export business strategy towards sustaining supply chain coordination and competitive advantage: Evidence from Vietnam's seafood processing firms. In *Environmental Sustainability in Emerging Markets* (pp. 95-126): Springer.

Do, B., Nguyen, U., Nguyen, N., & Johnson, L. W. (2019). Exploring the proactivity levels and drivers of environmental strategies adopted by vietnamese seafood export processing firms: A qualitative approach. *Sustainability, 11*(14), 3964.

Do, H. L., & Ho, T. Q. (2022). Climate change adaptation strategies and shrimp aquaculture: Empirical evidence from the Mekong Delta of Vietnam. *Ecological Economics, 196*, 107411.

DONRE. (2022). *About Can Tho Department of Natural Resources and Environment*. Retrieved from https://bom.so/DYnq0M

EFSA. (2008). Animal welfare aspects of husbandry systems for farmed trout: Scientific Opinion of the Panel on Animal Health and Welfare. *European Food Safety Authority, 6*(10), 796.

Elisabeth, D. v. W. (2016). *Boundary-work in sustainability certification a case study of the ASC standard on responsible shrimp farming*. Wageningen University.

FAO. (2012a). *Global trends and future challenges for the work of the organization*. FAO.

FAO. (2012b). *The state of world fisheries and aquaculture* (978-92-5-107225-7). Retrieved from Rome, Italy: https://pdf4pro.com/amp/download?data_id=146035&slug=the-state-of-world-fisheries-and-aquaculture-2012

FAO. (2014). *Policy and governance in aquaculture. Lessons learned and way forward.*

FAO. (2015). *Learning tool on nationally appropriate mitigation actions (NAMAs) in the agriculture, forestry and other land use (AFOLU) sector*. FAO.

FAO. (2019). *Promote scaling-up of innovative rice-fish farming and climate resilient Tilapia pond culture practices for blue growth*. Retrieved from https://www.fao.org/3/ca8695en/ca8695en.pdf

FAO. (2020). *The effect of COVID-19 on fisheries and aquaculture in Asia*. Retrieved from Bangkok: https://www.fao.org/documents/card/en/c/ca9545en

FAO. (2021). *The role of social protection in the recovery from COVID-19 impacts in fisheries and aquaculture*. Retrieved from Rome: https://www.fao.org/policy-support/tools-and-publications/resources-details/en/c/1382680/

FAO. (2022). *The state of world fisheries and aquaculture 2022*. Retrieved from Rome: https://www.fao.org/documents/card/en?details=cc0461en

FAO, & WorldFish. (2021). *Aquatic food systems under COVID-19*. Retrieved from Rome: www.fao.org/publications/card/en/c/CB5398EN

Fernandes, V., Sabu, E. A., Shivaramu, M. S., Gonsalves, M. J. B., & Sreepada, R. A. (2019). Dynamics and succession of plankton communities with changing nutrient levels in tropical culture ponds of whiteleg shrimp. *Aquaculture Environment Interactions, 11*, 639–655.

Fish Health Forum. (2021). Fish vaccination a key part of future success for world's largest pangasius producer. Retrieved from https://fishhealthforum.com/fish-vaccination-a-key-part-of-future-success-for-worlds-largest-pangasius-producer/

GAFS. (2018). *Fishing for equality: Why gender matters in aquaculture and fisheries*. Retrieved from https://www.genderequality.genderaquafish.org

Ganeshkumar, C., Jena, S. K., Sivakumar, A., & Nambirajan, T. (2021). Artificial intelligence in agricultural value chain: Review and future directions. *Journal of Agribusiness in Developing and Emerging Economies*. doi:10.1108/jadee-07-2020-0140

Gerland, P., Raftery, A. E., Ševčíková, H., Li, N., Gu, D., Spoorenberg, T., . . . Lalic, N. (2014). World population stabilization unlikely this century. *Science, 346*(6206), 234–237.

Goddek, S., Joyce, A., Kotzen, B., & Burnell, G. M. (2019). *Aquaponics food production systems: Combined aquaculture and hydroponic production technologies for the future*: Springer Nature.

Godfray, H., Beddington, J., Crute, I., Haddad, L., Lawrence, D., Muir, J., & Toulmin, C. (2010). *Food security: The challenge of feeding 9 billion people. science*.

Golden, C., Allison, E. H., Cheung, W., Dey, M. M., Halpern, B. S., McCauley, D. J., . . . Myers, S. S. (2016). Fall in fish catch threatens human health. *Nature, 534*(7607), 317–320.

Golden, C. D., Seto, K. L., Dey, M. M., Chen, O. L., Gephart, J. A., Myers, S. S., . . . Allison, E. H. (2017). Does aquaculture support the needs of nutritionally vulnerable nations? *Frontiers in Marine Science, 4*, 159.

Guillen, J., Natale, F., Carvalho, N., Casey, J., Hofherr, J., Druon, J.-N., . . . Martinsohn, J. T. (2019). Global seafood consumption footprint. *Ambio, 48*(2), 111–122.

Ha Van. (2022a). *Food safety, improving the quality of agro-forestry-fishery products, promoting trade*. *Can Tho*. Retrieved from https://baocantho.com.vn/an-toan-thuc-pham-nang-cao-chat-luong-nong-lam-thuy-san-thuc-day-giao-thuong--a152855.html

Ha Van. (2022b). *Protecting water resources in Can Tho city*. Retrieved from https://baocantho.com.vn/bao-ve-nguon-tai-nguyen-nuoc-o-tp-can-tho-a153585.html

Hai Dang. (2022). Can Tho University: 40-year journey and contributions to the fisheries industry. On *Science and Development*

Hai Minh. (2018). *Saving energy in aquaculture. SGGP*.

Hasan, M. R., & Shipton, T. A. (2021). Aquafeed value chain analysis of striped catfish in Vietnam. *Aquaculture, 541*(January), 736798–736798. doi:10.1016/j.aquaculture.2021.736798

Hoang, H. B. (2017). *Improving the competitiveness of Vietnamese seafood products in the EU market since Vietnam joined the World Trade Organization*. Vietnam Academy of Social Sciences.

Hoang Vu. (2020). Models of raising eel without mud combined with high-profit hydroponic vegetable farming. *Agriculture of Vietnam*. Retrieved from https://nongnghiep.vn/nhung-mo-hinh-nuoi-luon-khong-bun-ket-hop-trong-rau-thuy-canh-loi-nhuan-cao-d196490.html

Hoang Vu, & Hung Phu. (2017). Linking production of 3 levels of pangasius seed. *Agriculture of Viet Nam*.

Retrieved from https://nongnghiep.vn/lien-ket-san-xuat-giong-ca-tra-3-cap-d204713.html

Hong Phuong. (2020). *Seafood occupies a strong position in Can Tho's export foreign currency structure*. Retrieved from https://urlzs.com/eun5D

Hu, Z., Lee, J. W., Chandran, K., Kim, S., Sharma, K., & Khanal, S. K. (2014). Influence of carbohydrate addition on nitrogen transformations and greenhouse gas emissions of intensive aquaculture system. *Science of the Total Environment, 470*, 193–200.

Huynh Kim. (2022). Can Tho expands trade in agricultural and aquatic products. *Saigon Marketing*. Retrieved from https://www.sgtiepthi.vn/can-tho-mo-rong-giao-thuong-hang-nong-thuy-san/

ICAFIS. (2011). *ICAFIS - Training of auditors on the ASC Pangasius standards*. Retrieved from http://www.icafis.vn/en/icafis-training-auditors-asc-pangasius-standards

ICAFIS. (2015a). *Costs and benefits in applying ASC pangasius*.

ICAFIS. (2015b). *Training workshop on the promotion of improved on-farm shrimp feed management practices*. Retrieved from http://www.icafis.vn/flexpager/split_document.php?subfolder=&doc=tai_lieu_icafis_2_compatibility_mode.pdf

ICAFIS. (2016). *SUSV project organized: "Group Internal Auditing for Shrimp producer groups ASC standard"*. Retrieved from http://www.icafis.vn/en/susv-project-organized-group-internal-auditing-shrimp-producer-groups-asc-standard

ILO_Statistics on employment. (2022). *ILO, Statistics on employment*. Retrieved from https://ilostat.ilo.org/topics/employment/

JICA. (2016). *Outline of the project*. Retrieved from https://www.jica.go.jp/project/english/vietnam/039/outline/index.html

K.V. (2018). Can Tho actively responds to saline intrusion. *Government News*.

Kabeer, N. (1994). *Reversed realities: Gender hierarchies in development thought*: Verso.

Kautsky, N., Rönnbäck, P., Tedengren, M., & Troell, M. (2000). Ecosystem perspectives on management of disease in shrimp pond farming. *Aquaculture, 191*(1-3), 145–161.

Khanh An. (2022). *Can Tho applies saline intrusion monitoring and warning system*. Vietnam Clean Energy Association. Retrieved from https://nangluongsachvietnam.vn/d6/vi-VN/news/Can-Tho-ung-dung-he-thong-quan-trac-va-canh-bao-xam-nhap-man-6-179-17571

Khanh Trung. (2020a). Agricultural extension - support farmers to increase production efficiency. *Can Tho*. Retrieved from https://baocantho.com.vn/khuyen-nong-ho-tro-nong-dan-tang-hieu-qua-san-xuat-a125299.html

Khanh Trung. (2020b). Raising eels sells for a high price. *Can Tho*. Retrieved from https://baocantho.com.vn/nuoi-luon-ban-duoc-gia-cao-a122369.html

Khanh Trung. (2022). There is a lot of room in the development of trade between Can Tho city and Hanoi capital. *Can Tho*. Retrieved from https://baocantho.com.vn/nhieu-du-dia-trong-phat-trien-giao-thuong-giua-tp-can-tho-va-thu-do-ha-noi-a153210.html

Khanjani, M. H., Zahedi, S., & Mohammadi, A. (2022). Integrated multitrophic aquaculture (IMTA) as an environmentally friendly system for sustainable aquaculture: Functionality, species, and application of biofloc technology (BFT). *Environmental Science Pollution Research*, 1–19.

Kibria, G. (2004). *Gender roles in aquaculture: Some findings from the aquaculture development in the northern uplands of Viet Nam project.* FAO Aquaculture Newsletter.

Kobayashi, M., Msangi, S., Batka, M., Vannuccini, S., Dey, M. M., & Anderson, J. L. (2015). Fish to 2030: the role and opportunity for aquaculture. *Aquaculture economics management, 19*(3), 282–300.

Lai, T. P. (2008). Fisheries co-management in Vietnam: Issues and approach.

Lazur, A. (2007). *Growout pond and water quality management.* JIFSAN Good Aquacultural Practices Program, University of Maryland.

Le, H. (2021a). Can Tho City: Focus on implementing sustainable development goals according to Resolution No. 120/NQ-CP. *Natural Resources and Environment Newspaper.* Retrieved from https://rb.gy/np0ygy

Le, H. (2021b). Resolution 120 is a guideline for the development of Can Tho and the Viet Nam Mekong Delta region. *Natural Resources and Environment Newspaper.*

Le Hung, & Thanh Bach. (2022). Responding to saline intrusion in the Mekong Delta - current situation and solutions - Proactive, flexible, with many solutions. *MONRE News*.

Le, T. P., De Boer, I., & Udo, H. (2011). Life cycle assessment of food production in integrated agriculture–aquaculture systems of the Mekong Delta. *Livestock Science, 139*(1-2), 80–90.

Le, T. P., Stoorvogel, J., Van Mensvoort, M., & Udo, H. (2011). Modeling the soil nutrient balance of integrated agriculture-aquaculture systems in the Mekong Delta, Vietnam. *Nutrient Cycling in Agroecosystems, 90*(1), 33–49.

Le, T. T. H. (2019). *Analysis of the value chain and production efficiency of pangasius farming household in Vietnam Mekong Delta region.* [EDITOR'S NOTE: MISSING PUBLISHER]

Le, T. T. H., & Nguyen, H. N. (2021). *Hiện trạng phát thải khí nhà kính tại Việt Nam: Cơ hội và thách thức.*

Lebel, L., Lebel, P., Chitmanat, C., Uppanunchai, A., & Apirumanekul, C. (2018). Managing the risks from the water-related impacts of extreme weather and uncertain climate change on inland aquaculture in Northern Thailand. *Water International, 43*(2), 257–280.

Leigh, C., Le, H. H., Stewart‐Koster, B., Duong, M. V., Condon, J., Nguyen, V. S., . . . Burford, M. A. (2017). Concurrent rice‐shrimp‐crab farming systems in the Mekong Delta: Are conditions (sub) optimal for crop production and survival? *Aquaculture Research, 48*(10), 5251–5262.

Leigh, C., Stewart-Koster, B., Nguyen, V. S., Vo, B. X., Nguyen, T. N. T., Sammut, J., & Burford, M. A. (2020). Rice-shrimp ecosystems in the Mekong Delta: Linking water quality, shrimp and their natural food sources. *Science of the Total Environment, 739,* 139931.

Lem, A., Tietze, U., & Ruckes, E. (2004). *Fish marketing and credit in Viet Nam*. FAO.

Lentisco, A., & Lee, R. (2014). Beyond fish processors and caregivers: Women as primary, secondary and tertiary fish users. *Gender in aquaculture fisheries: Navigating change, 33.*

Linh Le. (2022). *Can Tho promulgates action plan on green growth for the period of 2021-2030.* Ministry of Industry and Trade of The Socialist Republic of Vietnam.

Linh Thuy. (2022). *Seafood industry adds more value from deep processing*. Retrieved from https://urlzs.com/UVjES

Luong, V. Q. D., Dang, V. M. D., Tran, H. D., & Nguyen, C. N. (2020). Design and deployment of an IoT-based water quality monitoring system for aquaculture in Mekong Delta. *International Journal of Mechanical Engineering*

Robotics Research, 9(8), 1170–1175.

Luu, D. D., Faggotter, S. J., Chen, C., Sammut, J., & Burford, M. A. (2019). Factors driving low oxygen conditions in integrated rice-shrimp ponds. *Aquaculture, 512*, 734315.

Luu, T. D. H. (2020). Market structure and value chain of pangasius industry in the Mekong Delta. *Journal of Asian Business and Economic Studies*, 42-45.

MacLeod, M. J., Hasan, M. R., Robb, D. H., & Mamun-Ur-Rashid, M. (2020). Quantifying greenhouse gas emissions from global aquaculture. *Scientific reports, 10*(1), 1–8.

Mai Ca. (2022). Seafood exports continue to increase strongly in markets with FTAs. Retrieved from https://trungtamwto.vn/chuyen-de/20267-xuat-khau-thuy-san-tiep-tuc-tang-manh-tai-cac-thi-truong-co-fta

Mai Hien. (2022). Digital transformation goes mainstream in Vietnam. *VietnamPlus*. Retrieved from https://en.vietnamplus.vn/digital-transformation-goes-mainstream-in-vietnam/220466.vnp

Manji, A. (2010). Eliminating poverty? 'Financial inclusion', access to land, and gender equality in international development. *Modern Law Review, 73*(6), 985–1004.

Mao, H.-L., Wang, J.-K., Zhou, Y.-Y., & Liu, J.-X. (2010). Effects of addition of tea saponins and soybean oil on methane production, fermentation and microbial population in the rumen of growing lambs. *Livestock Science, 129*(1-3), 56–62.

MARD. (2022). Statistical report. Retrieved from https://www.mard.gov.vn/Pages/bao-cao-thong-ke.aspx#

McIntyre, P. B., Reidy Liermann, C. A., & Revenga, C. (2016). Linking freshwater fishery management to global food security and biodiversity conservation. *Proceedings of the National Academy of Sciences, 113*(45), 12880–12885.

Miller, M. F. (2021). *The human dimensions of aquaculture development in Maine including a governance perspective*: University of Maine.

Minh Huyen. (2020). Developing more than 289ha of quality aquaculture areas. *Can Tho.* Retrieved from https://baocantho.com.vn/phat-trien-hon-289ha-vung-nuoi-thuy-san-chat-luong-a122796.html

Misk, R., & Gee, J. (2020). Women as agents of change in the response to COVID-19. *FAO Aquaculture Newsletter* (62), 50–52.

MOF. (2020). *Some changes in resource tax policy*. Retrieved from https://mof.gov.vn/webcenter/portal/btcvn/pages_r/l/tin-bo-tai-chinh?dDocName=BTC319184

MONRE. (2003). *Vietnam initial national communication: Under the United Nations Framework Convention on Climate Change*. Retrieved from Ministry of Natural Resources and Environment https://unfccc.int/resource/docs/natc/vnmnc01.pdf

Monsees, H., Suhl, J., Paul, M., Kloas, W., Dannehl, D., & Würtz, S. (2019). Lettuce (Lactuca sativa, variety Salanova) production in decoupled aquaponic systems: Same yield and similar quality as in conventional hydroponic systems but drastically reduced greenhouse gas emissions by saving inorganic fertilizer. *PLoS One, 14*(6), e0218368.

MPI. (2020). *Socio-economic situation in September 2020 in Can Tho city*. Retrieved from https://www.mpi.gov.vn/Pages/tinbai.aspx?idTin=48047&idcm=499

MPI. (2022a). Can Tho planning. Retrieved from https://quyhoachquocgia.mpi.gov.vn/Pages/tinvb.aspx?idTin=485

MPI. (2022b). Planning of the Mekong Delta region. Retrieved from https://quyhoachquocgia.mpi.gov.vn/Pages/tinvb.aspx?idTin=326

MRC. (2006). *Gender and fisheries in the Lower Mekong Basin*.

Mukhopadhyay, M. (2016). Mainstreaming gender or "streaming" gender away: feminists marooned in the development business. In *The Palgrave handbook of gender and development* (pp. 77-91): Springer.

My Thanh. (2021). Approving Can Tho City Agricultural Extension Program for the period of 2021-2025. *Can Tho*. Retrieved from https://baocantho.com.vn/phe-duyet-chuong-trinh-khuyen-nong-tp-can-tho-giai-doan-2021-2025-a134416.html

My Thanh. (2022). The production of harvested seafood has increased sharply. *Can Tho*. Retrieved from https://baocantho.com.vn/san-luong-thuy-san-thu-hoach-tang-manh-a147456.html

N. Hung. (2011). Disease outbreaks for intensive shrimp farming system according to climate change (in Vietnamese: Tôm b□ d□ch b□nh do bi□n đ□i khí h□u). *Kinh Te Sai Gon online*.

Nabeshima, K., Michida, E., Vu, H. N., & Suzuki, A. (2015). *Emergence of Asian GAPs and its relationship to global GAP*: Institute of Developing Economies, Japan External Trade Organization.

Naylor, R. L., Goldburg, R. J., Primavera, J. H., Kautsky, N., Beveridge, M., Clay, J., . . . Troell, M. (2000). Effect of aquaculture on world fish supplies. *Nature, 405*(6790), 1017–1024.

Ngan, D. (2022). Vietnam takes drastic and responsible actions to fulfill its commitments at COP26. *Investment newspaper*. Retrieved from https://urlzs.com/ubhZw

Nguyen, A. (2020a). Value-added products: An urgent direction of the seafood industry. *Vietnam Fisheries Magazine*. Retrieved from http://surl.li/efgbs

Nguyen, A. L., Dang, V. H., Bosma, R. H., Verreth, J. A., Leemans, R., & De Silva, S. S. (2014). Simulated impacts of climate change on current farming locations of striped catfish (Pangasianodon hypophthalmus; Sauvage) in the Mekong Delta, Vietnam. *Ambio, 43*(8), 1059–1068.

Nguyen, A. L., Truong, M. H., Verreth, J. A., Leemans, R., Bosma, R. H., & De Silva, S. S. (2015). Exploring the climate change concerns of striped catfish producers in the Mekong Delta, Vietnam. *Aquaculture, 4*(1), 1–8.

Nguyen, D. H. (2012). Gender issues in the fishery communities of the Central Coastal Provinces of Vietnam. *Gender in Aquaculture Fisheries: Moving the Agenda Forward*, 143129.

Nguyen, H. (2017). How to tap domestic seafood market potential [Press release]. Retrieved from http://ven.vn/how-to-tap-domestic-seafood-market-potential-29237.html

Nguyen, H. T. (2014). Possible impacts of seawater intrusion and strategies for water management in coastal areas in the Vietnamese Mekong delta in the context of climate change. In *Coastal disasters and climate change in Vietnam* (pp. 219-232): Elsevier.

Nguyen, M. H., & Nguyen, T. N. T. (2022). E-Commerce: Important pillar of Vietnam's digital economic development. *VietnamPlus*.

Nguyen, N. D., & Tran, T. B. (2005). Current status and measures to improve grassroots agricultural extension organizations in Soc Trang province.

Nguyen, N. T., Matsuhashi, R., & Vo, T. T. B. C. (2019). A sustainable energy model for shrimp farms in the Mekong Delta. *Energy Procedia, 157*, 926–938.

Nguyen, Q. T. (2018). Use of pesticides in fresh water aquaculture in the Mekong Delta, Vietnam, and impacts on environment and food safety.

Nguyen, T., Vu, N. U., & Merckx, R. (2011). Physico￾chemical characteristics of the improved extensive shrimp farming system in the Mekong Delta of Vietnam. *Aquaculture Research, 42*(11), 1600–1614.

Nguyen, T. A. T., & Jolly, C. M. (2020). Global value chain and food safety and quality standards of Vietnam pangasius exports. *Aquaculture reports, 16*, 100256. doi:https://doi.org/10.1016/j.aqrep.2019.100256

Nguyen, T. D., Ngo, T. T., & Nguyen, T. M. K. (2015). *Determinations of woman's contributions to fish and shrimp farms in Vietnam' northern coastal area.* Paper presented at the World Aquaculture Conference 26-30 May 2015, Jeju, Korea.

Nguyen, T. K. D., Nguyen, D. T., Tra, H. S., & Luong, H. D. K. (2015). *Automated monitoring and control system for shrimp farms based on embedded system and wireless sensor network*. Paper presented at the 2015 IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT).

Nguyen, T. K. Q., Tran, T. B. Y., & Riple, A. K. L. (2022). Adoption of Vietnamese Good Agricultural Practices (VietGAP) in aquaculture: Evidence from small-scale shrimp farming. *Asian Fisheries Science*.

Nguyen, T. K. Q., & Truong, H. M. (2014). Gender in rice-shrimp value chain: A case study of grow-out farm in Soc Trang Province, Vietnam. *5th Global Symposium on Gender in Aquaculture and Fisheries (GAF5).*

Nguyen, T. P. (2013). On-farm feed management practices for striped catfish (Pangasianodon hypophthalmus) in Mekong River Delta, Viet Nam. *On-farm eeding and feed management in aquaculture*, 241-267.

Nguyen, T. P., & Dang, T. H. O. (2010). Striped catfish aquaculture in Vietnam: a decade of unprecedented development. In *Success stories in Asian aquaculture* (pp. 131-147): Springer.

Nguyen, T. P., Tran, N. H., Tran, T. T. H., Tran, V. B., Do, T. T. H., Vu, N. S., . . . Wilder, M. N. (2006). Current status of freshwater prawn culture in Vietnam and the development and transfer of seed production technology. *Fisheries Science, 72*(1), 1–12. doi:10.1111/j.1444-2906.2006.01109.x

Nguyen Tuong, & Thanh Tam. (2022). Development of Logistics services in the Vietnam Mekong Delta region. *Vietnam Logistics Business Association*.

Nguyen, V. H. (2020b). Economic analysis of small scale freshwater aquaculture production and its product marketing channels in agro-aquaculture system in Hai Duong province, Vietnam.

Nguyen, V. S., & Tu, V. B. (2016). Aquaculture market and development strategy: The case of Pangasius in the Mekong Delta, Vietnam.

Nguyen, V. T., & Chanagun, C. (2021). Aquaculture production in Asian countries. In R. Nash, S. Shibaev, & R. Petkam (Eds.), *Aquacultutre with a focus on Vietnam and Thailand*. Wolfsburg: Ostfalia Hochschule für angewandte Wissenschaften Braunschweig/ Wolfenbüttel.

Nguyen, V. T., & Vo, T. D. (2014). Vietnam Pangasius market: value chain income distribution - Production cost per unit - Industry development solutions. *Can Tho University Journal of Science*(32), 38–44.

Nhat Linh. (2022). Selection of salt-tolerant pangasius varieties. *Aquaculture Vietnam*. Retrieved from https://aquaculture.vn/khoa-hoc-ky-thuat/chon-loc-giong-ca-tra-chiu-man

Nhu, T. T. (2017). *Environmental sustainability assessment of fish products from aquaculture in Vietnam: a focus on Pangasius hypophthalmus*. Ghent University,

NIPTEX. (2019). *Automatic fish feeder with IoT technology*. Retrieved from http://niptex.gov.vn/en/nam-2019/thang-5/856-may-cho-ca-an-tu-dong-tich-hop-cong-nghe-iot

Nuruzzaman, M., Selim, S. U. M., & Miah, M. H. (2014). Rights, benefits and social justice: Status of women workers engaged in the shrimp processing industries of Bangladesh. *Asian Fisheries Science Special Issue*.

OCED. (2015). *OECD food and agricultural reviews agricultural policies in Viet Nam 2015*: OECD Publishing.

OCED. (2020). Sustainable fisheries and aquaculture policies for the future. *Fisheries and aquaculture,*. Retrieved from https://www.oecd.org/agriculture/topics/fisheries-and-aquaculture/

Okunogbe, A., Hähnle, J., Rotimi, B. F., Akande, T. M., & Janssens, W. (2022). Short and longer-term impacts of health insurance on catastrophic health expenditures in Kwara State, Nigeria. *BMC Health Services Research, 22*(1), 1–18.

Open Development Vietnam. (2022). New normal: Mekong Delta faces drought and saltwater intrusion. Retrieved from https://vietnam.opendevelopmentmekong.net/vi/topics/droughts-and-saltwater-intrusion/

Osborne, M. (2009). *The Mekong: River under threat*: New South Wales Australia: Lowy Institute for International Policy.

Ozaki, H., Co, T. K., Le, A. K., Pham, V. N., Nguyen, V. B., Tarao, M., . . . Sagehashi, M. (2014). Human factors and tidal influences on water quality of an urban river in Can Tho, a major city of the Mekong Delta, Vietnam. *Environmental monitoring assessment, 186*(2), 845–858.

Pham, C. D., Vo, Q. M., & To, D. K. (2021). *Assessing the status and potential of developing the One Commune One Product (OCOP) program in Can Tho city*.

Pham, D. K. (2020). Cần Thơ sẽ trở thành trung tâm thuỷ sản của ĐBCSL vào năm 2020. *Aquaculture Vietnam,*. Retrieved from https://thuysanvietnam.com.vn/can-tho-se-thanh-trung-tam-thuy-san-cua-dbscl-vao-nam-2020/

Pham, T. A., Bush, S. R., Mol, A. P., & Kroeze, C. (2011). The multi-level environmental governance of Vietnamese aquaculture: global certification, national standards, local cooperatives. *Journal of Environmental Policy Planning, 13*(4), 373–397. doi:https://doi.org/10.1080/1523908X.2011.633701

Phan Anh. (2017). *Earn billions every year by raising eels without mud according to VietGAP standards*. Retrieved from https://tepbac.com/tin-tuc/full/thu-tien-ty-moi-nam-nho-nuoi-luon-khong-bun-theo-tieu-chuan-vietgap-21917.html

Phan, M. T., Huynh, M. S., & Hua, T. A. (2021). Mariculture in southern central region, Vietnam: Status and orientation toward sustainable development. *Journal of Agriculture Ecology Research International*, 28–37.

Phan, V. C. (2020). Seafood processing industry - Development potential and problems for Can Tho city. *Electronic Political Theory Magazine*. Retrieved from https://urlzs.com/wRmc9

Phan, V. T., Nguyen, T. H. P., Do, T. T. H., & Nguyen, T. P. (2014). Effect of temperature on physiology and growth of fingerling catfish (Pangasianodon Hypophthalmus). *Scientific Journal of Can Tho University* (College No. Fisheries 2014), 292–301.

Picciotti, A. (2017). Towards sustainability: The innovation paths of social enterprise. *Annals of Public Cooperative Economics, 88*(2), 233–256.

Raul, C., Pattanaik, S. S., & Prakash, S. (2020). Greenhouse gas emissions from aquaculture systems. *World Aquaculture, 57*, 61.

Robb, D. H., MacLeod, M., Hasan, M. R., & Soto, D. (2017). *Greenhouse gas emissions from aquaculture: A life cycle assessment of three Asian systems.* FAO Fisheries Aquaculture Technical Paper (609).

Robertson, C. (2006). *Australian prawn farming manual: Health management for profit*.

Sasi, S., Prasad, K., Weerasinghe, J., Bazaka, O., Ivanova, E. P., Levchenko, I., & Bazaka, K. (2022). Plasma for aquaponics. *Trends in Biotechnology*.

Sathoria, P., & Roy, B. (2022). Sustainable food production through integrated rice-fish farming in India: A brief review. *Renewable Agriculture Food Systems*, 1–9.

Sena S. De Silva, & Doris, S. (2009). Climate change and aquaculture: Potential impacts, adaptation and mitigation. In Kevern Cochrane, Cassandra De Young, Doris Soto, & T. Bahri (Eds.), *Climate change implications for fisheries aquaculture: overview of current scientific knowledge*. Rome, Italy: FAO Fisheries Aquaculture Technical Paper.

Simbeye, D. S., Zhao, J., & Yang, S. (2014). Design and deployment of wireless sensor networks for aquaculture monitoring and control based on virtual instruments. *Computers Electronics in Agriculture, 102*, 31–42.

Spångberg, J., Tidåker, P., & Jönsson, H. (2014). Environmental impact of recycling nutrients in human excreta to agriculture compared with enhanced wastewater treatment. *Science of the Total Environment, 493*, 209–219.

Statistical Office of Can Tho. (2022). Statistical Office of Can Tho. Retrieved from https://thongkecantho.gso.gov.vn/

Stazi, A., & Jovine, R. (2022). Food traceability in Europe, the US and China: Comparative law and regulatory technology. *BioLaw Journal* (2).

Ström, G. H., Björklund, H., Barnes, A. C., Chau, T. D., Nguyen, H. Y. N., Trinh, T. L., . . . Boqvist, S. (2019). Antibiotic use by small scale farmers for freshwater aquaculture in the Upper Mekong Delta, Vietnam. *Journal of Aquatic Animal Health, 31*(3), 290–298. doi:10.1002/aah.10084

Sze Choo, P., Nowak, B. S., Kusakabe, K., & Williams, M. J. (2008). Guest editorial: Gender and fisheries. *Development, 51*(2), 176–179.

T.Anh. (2022). Green transition: An inevitable trend to develop the seafood industry. Retrieved from https://kinhtemoitruong.vn/chuyen-doi-xanh-xu-huong-tat-yeu-de-phat-trien-nganh-thuy-san-69866.html

Takagi, H., Tran, V. T., & Nguyen, D. T. (2014). Investigation on floods in Can Tho City: Influence of ocean tides and sea level rise for the Mekong Delta's largest city. In *Coastal Disasters and Climate Change in Vietnam* (pp. 257–274): Elsevier.

Tam Phuong. (2022). Can Tho city concretizes Resolution No. 120/NQ-CP into life. *Institute of Strategy, Policy on Natural Resources and Environment*. Retrieved from https://rb.gy/ez54ua

Tessler, Z., Vörösmarty, C. J., Grossberg, M., Gladkova, I., Aizenman, H., Syvitski, J. P., & Foufoula-Georgiou, E. (2015). Profiling risk and sustainability in coastal deltas of the world. *Science, 349*(6248), 638–643.

Thai Cuong. (2022). *The ceremony to release fingerlings to regenerate the inter-provincial aquatic resources of An Giang-Can Tho-Dong Thap, on the Hau River in 2022*. Retrieved from https://angiang.gov.vn/wps/wcm/connect/an+giang+portal-vi/sa-tintuc/le-tha-ca-giong-tai-tao-nguon-loi-thuy-san-lien-tinh-an-giang-can-tho-dong-thap-tren-song-hau-nam-2022

Thanh Hoa. (2020). Fishery logistics management. *Nam Dinh*. Retrieved from http://baonamdinh.vn/channel/5085/202006/quan-ly-dich-vu-hau-can-nghe-ca-2538150/

Thanh Thuy. (2021). *Can Tho: Total seafood production in the first 6 months of the year is estimated at 77,000 tons, up 4% over the same period*. Retrieved from https://tongcucthuysan.gov.vn/vi-vn/khai-th%C3%A1c-th%E1%BB%A7y-s%E1%BA%A3n/doc-tin/015928/2021-06-15/can-tho-tong-san-luong-thuy-san-trong-6-thang-dau-nam-uoc-dat-77000-tan-tang-4-so-voi-cung-ky

Thanh Vu. (2022). Can Tho applies science and technology in aquaculture. *Environmental economics*. Retrieved from https://kinhtemoitruong.vn/can-tho-ung-dung-khoa-hoc-cong-nghe-trong-nuoi-trong-thuy-san-71027.html

Thu Hien. (2022). Hanoi and Can Tho seek ways to improve the quality of agricultural, forestry and fishery trade. *Bnews*. Retrieved from https://bnews.vn/ha-noi-va-can-tho-tim-huong-nang-cao-chat-luong-nong-lam-thuy-san-giao-thuong/264441.html

Thu Hoa. (2021). Application of science and technology in aquaculture. *Numbers & Facts Magazine*. Retrieved from https://consosukien.vn/u-ng-du-ng-khoa-ho-c-cong-nghe-trong-nuoi-tro-ng-thu-y-sa-n.htm

Thuy An. (2021). Vietnam Mekong Delta region: E-commerce and people's agricultural products.

Thuy, T. (2021). *Can Tho: Total seafood production in the first 6 months of the year is estimated at 77,000 tons, up 4% over the same period*. Retrieved from https://tongcucthuysan.gov.vn/vi-vn/khai-th%C3%A1c-th%E1%BB%A7y-s%E1%BA%A3n/doc-tin/015928/2021-06-15/can-tho-tong-san-luong-thuy-san-trong-6-thang-dau-nam-uoc-dat-77000-tan-tang-4-so-voi-cung-ky

Tong, T. A. N., Jacxsens, L., Noseda, B., Samapundo, S., Nguyen, B. L., Heyndrickx, M., & Devlieghere, F. (2014). Evaluation of the microbiological safety and quality of Vietnamese Pangasius hypophthalmus during processing by a microbial assessment scheme in combination with a self-assessment questionnaire. *Fisheries Science, 80*(5), 1117–1128.

Tran, M. P., Nguyen, T. P., Scippo, M. L., & Dalsgaard, A. (2015). Quality of antimicrobial products used in striped catfish (Pangasianodon hypophthalmus) aquaculture in Vietnam. *PLoS One, 10*(4), 1–8. doi:10.1371/journal.pone.0124267

Tran, M. P., Nguyen, T. P., Tu, T. D., Dao, M. H., Vo, N. S., Rico, A., . . . Dalsgaard, A. (2016). An evaluation of fish health-management practices and occupational health hazards associated with Pangasius catfish (Pangasianodon hypophthalmus) aquaculture in the Mekong Delta, Vietnam. *Aquaculture Research, 47*(9), 2778–2794. doi:10.1111/are.12728

Tran, T. N. T., & Nguyen, T. P. (2015). The impact of climate change on salinity intrusion and Pangasius (Pangasianodon Hypophthalmus) farming in the Mekong Delta, Vietnam. *Aquaculture International, 23*(2), 523–534.

Tran, T. T., Ly, N., & Nguyen, D. T. (2021). Survey on the case study of applying cold chain of agricultural product (vegetable, tubers, fruits) in Can Tho city. *Can Tho University Journal of Science, 57*(5), 292–303.

Trifković, N. (2014). Certified standards and vertical coordination in aquaculture: the case of pangasius from Vietnam. *Aquaculture, 433*, 235–246.

Trifković, N. (2016). Vertical coordination and farm performance: evidence from the catfish sector in Vietnam. *Agricultural Economics, 47*(5), 547–557.

Truong, T. N. C., & Yamada, R. (2002). Factors affecting farmers' adoption of technologies in farming system: A case study in Omon district, Can Tho province, Mekong Delta. *Omonrice, 10*, 94–100.

Tsai, M.-F., Kou, G.-H., Liu, H.-C., Liu, K.-F., Chang, C.-F., Peng, S.-E., . . . Lo, C.-F. (1999). Long-term presence of white spot syndrome virus (WSSV) in a cultivated shrimp population without disease outbreaks. *Diseases of Aquatic Organisms, 38*(2), 107–114.

UNFCCC. (2015). Vietnam Submits its Climate Action Plan Ahead of 2015 Paris Agreement. Retrieved from https://unfccc.int/news/vietnam-submits-its-climate-action-plan-ahead-of-2015-paris-agreement

UNFCCC. (2022). Introduction to Mitigation. Retrieved from https://unfccc.int/topics/introduction-to-mitigation

USAID. (2013). *USAID country profile. Property rights and resource governance, Vietnam*. Retrieved from https://urlzs.com/NCkcr

VASEP. (2018a). Can Tho: Pangasius farming area according to good practice standards tends to increase. Retrieved from https://tinyurl.com/4bw3n756

VASEP. (2018b). Vinh Hoan Corp and PHARMAQ signed a long-term agreement on vaccination program for Vietnamese pangasius. Retrieved from https://tinyurl.com/3v5dews9

VASEP. (2019). Technical Application Multiplex Realtime PCR in microbiological testing of seafood. Retrieved from https://tinyurl.com/2nkchyes

VASEP. (2021a). Can Tho City: Co Do develops freshwater aquaculture model.

VASEP. (2021b). Climate change and the future of shrimp and catfish. Retrieved from https://urlzs.com/xkPo6

VASEP. (2022). *Operation Report 2021-2022 and Operation Orientation 2022-2023*. Retrieved from https://urlzs.com/bfPTR

VASEP.PRO. (2017). *Summary of project establishing a sustainable pangasius supply chain in Vietnam (SUPA)*. Retrieved from https://tinyurl.com/3m27v29w

VASEP.PRO. (2020). Training course K19.20: Traceability for the production and supply chain of aquatic products - Requirements and solutions for developing applications. Retrieved from https://tinyurl.com/yc5db6fk

VASEP.PRO. (2022a). Combined workshop: Capacity building for energy managers in the seafood processing industry. Retrieved from https://tinyurl.com/yc22tpk3

VASEP.PRO. (2022b). Forum "Remove difficulties for seafood enterprises - insider's perspective". Retrieved from https://tinyurl.com/4euem5az

Vaughan, A. (2021). Global demand for fish expected to almost double by 2050. *New Scientist*. Retrieved from https://www.newscientist.com/article/2290082-global-demand-for-fish-expected-to-almost-double-by-2050/

VAWR. (2011). The Mekong Delta was heavily damaged by floods. Retrieved from https://vawr.org.vn/dong-bang-song-cuu-long-thiet-hai-nang-ne-do-lu

VCEA. (2022). Can Tho applies aquaculture to many quality standards. *Vietnam Clean Energy Association*. Retrieved from https://nangluongsachvietnam.vn/d6/vi-VN/news/Can-Tho-ung-dung-nuoi-trong-thuy-san-dat-nhieu-quy-chuan-chat-luong-0-1961-17356

Veliu, A., Gessese, N., Ragasa, C., & Okali, C. (2009). Gender analysis of aquaculture value chain in Northeast Vietnam and Nigeria.

VEM. (2021). Pilot conversion to eco-industrial park model at Tra Noc Industrial Park 1&2 (Can Tho). Retrieved from https://tinyurl.com/2rmz7dab

VietGAP. (2014). Welcome to information page vietgap.com. *introduce.* Retrieved from http://www.vietgap.com/1551/cm/gioi-thieu.html

Vietnamese Government. (2017). *Vietnamese Government Resolution No.120/ND-CP: "Sustainable development of the Viet Nam Mekong Delta in response to climate change"*. Retrieved from https://rb.gy/z6ehe1

Vietnamese Government. (2021a). *Draft decree on a number of fisheries development policies*. Retrieved from https://thuvienphapluat.vn/van-ban/Linh-vuc-khac/Nghi-dinh-ve-chinh-sach-phat-trien-thuy-san-477968.aspx

Vietnamese Government. (2021b). *Government Desicion No.339/QĐ-TTg: "Approving the strategy for development of Vietnam's fisheries by 2030 with vision towards 2045"* Retrieved from https://urlzs.com/ivtC4

Vietnamese Government. (2022a). *Nationally Determined Contribution (NDC)*. Retrieved from https://unfccc.int/documents/622541

Vietnamese Government. (2022b). *Vietnamese Government Plan No.200/KH-UBND: "Action on green growth period of 2021 - 2030, vision 2050 in can tho city"*. Retrieved from https://urlzs.com/4U2f9

Vinacert. (2017). Certificate ASC, MSC ,COC. Retrieved from http://www.vinacert.vn/vi/chung-nhan-asc-msc

VNA. (2018). 'One commune one product' scheme helps boost rural economic development. *Can Tho*. Retrieved from https://baocantho.com.vn/-one-commune-one-product-scheme-helps-boost-rural-economic-development-a97933.html

VNCPC. (2015). Four decisive factors for the success in applying cleaner production in seafood enterprises. Retrieved from https://vncpc.org/bon-yeu-to-quyet-dinh-den-su-thanh-cong-trong-viec-ap-dung-san-xuat-sach-hon-tai-cac-doanh-nghiep-thuy-san/

VNCPC. (2017). *Mainstreaming sustainable practices along Vietnam pangasius supply chain and strengthening green market link in EU*. Retrieved from https://tinyurl.com/5f965etk

VNCPC. (2020). Guidelines for sustainable consumption and production in the seafood processing in Vietnam. Retrieved from https://tinyurl.com/2s34d26u

VNCPC. (2021). *Annual report 2021 of VNCPC*. Retrieved from https://urlzs.com/WEQX8

VNCPC. (n.d.). Establishing a sustainable Pangasius supply chain in Vietnam (SUPA). Retrieved from https://vncpc.org/en/project/establishing-a-sustainable-pangasius-supply-chain-in-vietnam-supa-3/#toggle-id-1

Vo, T. T. E., Ko, H., Huh, J.-H., & Park, N. (2021). Overview of solar energy for aquaculture: The potential and future trends. *Energies, 14*(21), 6923.

Voeten, J., & Ottens, B.-J. (1997). Gender training in aquaculture in Northern Vietnam: A report. *Gender, Technology Development, 1*(3), 413–432.

Vu, N. U., Tran, M. P., & Tran, N. H. (2022). *New achievements in aquatic science and technology*. Retrieved from Faculty of Fisheries - Can Tho University: https://sdmd2045.ctu.edu.vn/images/news/062022/VNUt%20B%C3%A1o%20c%C3%A1o%20th%C3%A0nh%20t%C6%B0u%20KHCN%20Th%E1%BB%A7y%20s%E1%BA%A3n_final.pdf

Wang, Y., Liu, Y., & Gu, B. (2022). COP26: Progress, Challenges, and Outlook. *Advances in Atmospheric Sciences, 39*(8), 1209–1216. doi:https://doi.org/10.1007/s00376-022-2097-z

Weeratunge-Starkloff, N., & Pant, J. (2011). Gender and aquaculture: Sharing the benefits equitably.

Wilkes, A., Tennigkeit, T., & Solymosi, K. (2013). National planning for GHG mitigation in agriculture: A guidance document. *Mitigation of Climate Change in Agriculture Series* (8).

Wilkes A, T. T., Solymosi K (2013). National planning for GHG mitigation in agriculture: A guidance document. Mitigation of Climate Change in Agriculture Series 8. FAO.

Williams, M. J., Chao, N., Choo, P., Matics, K., Nandeesha, M., Shariff, M., . . . Wong, J. (2002). *Global Symposium on Women in Fisheries: Sixth Asian Fisheries Forum* (Vol. 1663): WorldFish.

Williams, S. B., Hochet-Kibongui, A.-M., & Nauen, C. E. (2005). *Gender, fisheries and aquaculture: Social capital and knowledge for the transition towards sustainable use of aquatic ecosystems*: EUR-OP.

World Bank. (2022). *GNI per capita, PPP (current international $)*. Retrieved from https://data.worldbank.org/indicator/NY.GNP.PCAP.PP.CD?end=2021&start=2011

WorldFish, FAO, & Duke University (2018). *Illuminating hidden harvests: A snapshot of key findings into the contributions of small-scale fisheries to sustainable development*. Retrieved from Rome, FAO, Durham, USA, Duke University, and Penang, Malaysia, WorldFish: http://pubs.iclarm.net/resource_centre/Program-Brief-Illuminating-hidden-harvests.pdf

Yogev, U., & Gross, A. (2019). Reducing environmental impact of recirculating aquaculture systems by introducing a novel microaerophilic assimilation reactor: modeling and proof of concept. *Journal of Cleaner Production, 226*, 1042–1050.

Annex

Annex 1: Number of operational farms in the main catfish farming provinces of the Mekong Delta in 2015

Production facilities		Provinces										Total
		An Giang	Dong Thap	Can Tho	Vinh Long	Ben Tre	Hau Giang	Tien Giang	Soc Trang	Tra Vinh	Tay Ninh	
Hatcheries	**Number**	16	77	2	4	4	2	3	1	0	0	109
	Capacity (million/annum)	2200	19,000	600	350	370	15	1134	2	0	0	23,671
Nurseries	Number	302	1676	105	68	4	10	500	0	5	13	2683
	Capacity (million/annum)	684	1200	380	53	45	2	204	0	5	9	2582
Grow-out ponds	**Pond area** (ha)	720	2040	831	431	720	147	122	100	11	48	5170
	Production (tonnes/annum)	243,581	372,146	150,634	96,180	160,000	47,613	36,014	24,500	4190	8939	1,143,797
Feed	**Number**	2	26	7	5	1	1	4	0	2	0	48
Manufacturing	**Installed**	90,000	3,310,000	600,000	170,500	106,000	106,000	700,000	0	150,000	0	5,232,500
Plants	**Capacity** (tonnes/annum)											
Feed ingredient suppliers	**Number**	0	75	3	0	0	0	0	0	0	0	78
Feed wholesalers/ retailers	**Number**	135	103	126	48	125	150	33	2	25	135	882
Fish processing	**Number**	23	20	40	1	3	4	19	0	1	1	112
Facilities	**Installed**	320,000	429,800	582,840	5583	1200	40,000	159,000	0	13,571	8000	1,519,974
	Capacity (tonnes/annum)											

Source: *Mohammad R. Hasan & Shipton (2021)*

Annex 2: Regulators in aquaculture system in Can Tho

	Organizations	Outstanding activities in the seafood industry	Results/Effectiveness of each activity	Achievements of activities	Limitations of activities
1	Ministry of Agriculture and Rural Development	2014-present: Promulgating the Code of Good Aquaculture Practices in Vietnam (VietGAP).	**Import-Export**: Supply seafood products with quality standards to meet the requirements of the export market. **Enterprises**: Improve product value and quality. **Farmers**: Increase income from commercial sources and reduce the cost of chemicals and feed. **Consumers**: Create trust and product quality for buyers of seafood products. **Environment**: Minimize ecological pollution (not using aquatic drugs harmful to the environment) (VietGAP, 2014).	Can Tho reached about 325 ha of VietGAP and nearly 14 ha of BAP + ASC (Thanh Thuy, 2021). There are 4 companies, 2 standard cooperatives, 2 pangasius farming cooperatives with an area of 27 ha, 99 households raising seafood according to VietGap, and 35 households participating in production association with factories with an area of 95 ha, 9 enterprises engaged in pangasius farming with an area of 129 ha) (Minh Huyen, 2020).	Smallholder farmers in aquaculture areas still often produce according to customs and traditions, so it is very difficult to influence and direct farmers to apply VietGAP production methods. This is also the cause that greatly and directly affects the quality and output of aquaculture households, leading to difficulties in product consumption (DARD, 2020).
		2022 – 2025: "Ensure food safety, improve agriculture, forestry and fishing quality between Can Tho city and other provinces in the country" program (DARD, 2022).	**Enterprises**: Promote cooperation, link production with consumption between Can Tho city and VMD provinces; **Consumers**: Quality, ensure food safety for consumers (DARD, 2022).		
2	Directorate of Fisheries	Tax policy: Restore the resource exploitation tax policy for fishing activities (MOF, 2020).	**Enterprises**: Ensure fairness in fishing activities (on the principle that a lot of fishing, which is an exploitation that causes damage to resources, the environment and marine ecosystems, has to pay a lot of tax). **Laborers**: Implement capital policies for fishing activities so that ship owners can invest in upgrading their vehicles, renewing technology, changing careers in an environmentally friendly manner, etc. (MOF, 2020).	In 2021, Can Tho aquaculture stock was 3.217 ha, up 1% over the same period in 2020, reaching 38% of the year's plan (Thuy, 2021). The mining output was 1,200 tons, exceeding 36% over the same period, reaching 50% of the year's plan. In general, total aquaculture production and exploitation of the Can Tho city is estimated to reach 77,000 tons, exceeding 4% over the same period (My Thanh, 2022).	Illegal unreported and unregulated fishing still exists, and the issued regulations have little impact on the deterrent and handling of violations (DARD, 2022).

	Organizations	Outstanding activities in the seafood industry	Results/Effectiveness of each activity	Achievements of activities	Limitations of activities
	Directorate of Fisheries	Policy on logistics facilities: Continue to deploy fishery logistics service facilities, such as fishing ports, fishing wharfs, leading legal support (Thanh Hoa, 2020).	**Import-Export**: Ensure offshore fishing services and quality seafood products penetrate into fastidious markets. **Enterprises**: Ensure the quality of fishery products. **Laborers**: Create favorable conditions in the loading of fish, selling fishermen's fish, and minimizing the waiting time for fish. **Consumers**: Enhance the quality of seafood products. **Environment**: Using timely logistics will avoid the amount of unusable seafood released into the environment, leading to emissions when it is decomposed (Thanh Hoa, 2020).		
		Policy in fishery extension: Improve fishery extension work, strengthen policy extension work to preserve post-harvest products, and specialize in assigning fishing methods that are less harmful to aquatic resources (OCED, 2015).	**Laborers**: Ensure fishing gear is highly selective, environmentally friendly, minimizes catching of rare and precious species while increasing the economic efficiency of fishing and promoting the benefits of workers (OCED, 2015).		
		Support policies in fishing: Reduce direct support policies, but still maintain oil support policies for offshore fishing activities. Develop a roadmap, join legal management organizations in the region and the world (Vietnamese Government, 2021a).	**Import-Export**: Moving toward seafood export standards. **Enterprises**: Being supported and prioritized for export (typically Decision 2007/QD-TCHQ extending the application of priority regime in the field of customs for Can Tho Seafood Import-Export Joint Stock Company). **Laborers**: Create alternative livelihoods for people (Vietnamese Government, 2021a).		

	Organizations	Outstanding activities in the seafood industry	Results/Effectiveness of each activity	Achievements of activities	Limitations of activities
	Directorate of Fisheries	Trade promotion policies: Join world standard organizations on environmental assurance, food hygiene and safety in order to obtain international certificates of Vietnam's caught fishery products (Vinacert, 2017).	**Enterprises**: Some businesses have overcome technical barriers to penetrate difficult but potential markets in the world such as the US, Japan, and the EU (Hoang, 2017); **Laborers**: Dynamic seafood export activities lead to many workers having jobs in the industry (Vinacert, 2017).		
		2022–2025: Organizing fish stocking to regenerate inter-provincial aquatic resources in An Giang - Can Tho - Dong Thap (total cost of 1.5 billion VND) (Thai Cuong, 2022).	Ensure fishing resources for fishermen. Encourage fishermen toward reasonable, efficient, stable and sustainable fishing (Thai Cuong, 2022).		
		2017–present: Joint production of high-quality three-level pangasius fish is concentrated in three provinces of An Giang, Ben Tre, Dong Thap and Can Tho city (Hoang Vu & Hung Phu, 2017).	**Enterprises**: Guarantees million the source of pangasius raw materials for businesses, creating favorable conditions for hatcheries to access technology, aiming at seed quality. **Laborers**: Create jobs for business people, rearing seeds at home in An Giang, Ben Tre, Dong Thap, and Can Tho City (Hoang Vu & Hung Phu, 2017).		
		Approve projects and programs on fishery extension, VietGAP, food safety and hygiene, environmental monitoring (Decision No. 27/2017/QD-TTg)	**Import-Export**: Approach and cooperate to ensure export standards and seafood quality. **Enterprises**: Create opportunities to enter the international market **Fishery extension policy**: Provide motivation, and create jobs for people to increase production and aquaculture. **Consumers**: Build confidence in consuming products of seafood brands. **Environment**: Stabilize the environment and promptly overcome problems with water sources and climate (Decision No. 27/2017/QD-TTg).		

	Organizations	Outstanding activities in the seafood industry	Results/Effectiveness of each activity	Achievements of activities	Limitations of activities
3	Can Tho Department of Agriculture and Rural Development	2016–present: Develop a safe agricultural, forestry and fishery supply chain model (Huynh Kim, 2022).	**Enterprises**: Supply agricultural, forestry ,and aquatic food products from Can Tho city to new markets. **Laborers**: Build and replicate many effective models, such as raising scads, snakeheads, catfish, perch, slices, eels, etc., in the direction of safety, using industrial feed instead of fresh food. **Consumers**: Provide a timely supply of seafood products to consumers throughout the country (Ha Van, 2022a).	In many districts such as Cai Rang, Binh Thuy, Phong Dien, Thoi Lai, and Co Do, the production and trading establishment of all kinds of aquatic breeds have developed quite strongly in recent years (Decision No. 102/ QD-UBND Can Tho). 92 OCOP products 3 stars, 4 stars, 5 safe food supply chains (Thu Hien, 2022); 99 safe agricultural, forestry and fishery food supply chains with 260 products confirmed in the chain (Khanh Trung, 2022).	The OCOP program has many complicated procedures with proof of origin of raw materials, quality, product standards, environmental protection, etc., so the research and product implementation process takes a long time (Pham *et al.*, 2021).
		2018–present: One Commune One Product Program (OCOP) (VNA, 2018).	**Import-Export**: Attract foreign partners through product quality and output response. **Laborers**: Increase production value and specialization in each region (VNA, 2018).		
4	Can Tho Department of Natural Resources and Environment	Check and supervise the monitoring program (aquaculture, fishing, seafood processing, aquatic infrastructure) (DONRE, 2022).	**Enterprises**: Ensure product output quality. **Environment**: Stabilize the water environment. **Laborers**: Make a significant contribution in providing complete and timely information to the people. From the results of analysis and assessment of water quality indicators, recommendations and suggestions will be made to promptly take corrective measures to minimize risks to farmers (DONRE, 2022).	Deploy and install automatic salinity monitoring equipment at 3 locations: Cai San bridge, Xa No canal, and Cai Cui port (Khanh An, 2022).	Implemented but not effective on environmental protection in seafood in Can Tho. The total budget for the monitoring project at Can Tho in excess of the granted level is VND 2,738,500,000 (for 5 years, from 2016 to 2020) (Can Tho Fisheries Sub-Department, 2020).
		2015–present: Building a List of Water Sources Requiring Protection Corridors in Can Tho city program (Ha Van, 2022b).	**Laborers**: Provide a sufficient water supply for aquaculture activities. **Environment**: Provide water protection (Ha Van, 2022b).		
		2021–present: Building a Disaster Risk Map Caused by Climate Change and Strengthening the Network of Monitoring and Warning of Saltwater Intrusion in Can Tho city project (Khanh An, 2022).	**Laborers**: Help aquaculture farmers easily cope with risks in aquaculture. **Environment**: Provide timely warning of environmental problems, thereby finding solutions (Khanh An, 2022).		

	Organizations	Outstanding activities in the seafood industry	Results/Effectiveness of each activity	Achievements of activities	Limitations of activities
5	Can Tho Fisheries Sub-Department	2022: Conduct a survey to select households to deploy a demonstration model and deploy 3 training courses on commercial eel farming according to the VietGAP-oriented food safety chain (Dieu Tam, 2022).	**Laborers**: Improve knowledge and income for households in the area, and form an expanded supply chain for seafood businesses. **Enterprises**: There is a source of quality eels to supply supermarkets (Dieu Tam, 2022).	Commercial eel is currently being sold by Metro Can Tho supermarket with a selling price that is always higher than the market price. This model of raising eel is now very effective, and some supermarkets now come to order (Phan Anh, 2017). This demonstration model in Thoi Lai and Co Do districts opens a new economic development direction for people, with yields of 1.2 tons/ha and profits over 40 million VND/year (Khanh Trung, 2020b). Phuoc Loc Hoa Cooperative in Thanh Phu Commune, Co Do District, Can Tho city, has 10 households raising eel without mud, of which there are 4 households with 64 tanks according to VietGAP standards combined with hydroponic vegetable growing. This eel farming model is now very effective. Metro Can Tho supermarket sells it at a price that is always higher than the market price (Hoang Vu, 2020).	Investment capital resources are limited. While the eel farming model has spread, the main source of output is supermarkets looking for hidden risks on supply-demand imbalance.
		Inspect and evaluate surface water quality and collect samples for environmental monitoring.	**Environment**: Timely assess the possibility of disease and solutions for the concentrated cage farming areas at points in the Hau river basin from Thoi An ward - O Mon district to Tan Loc ward - Thot Not district (Can Tho City People's Committee, 2021).		
		Create a model of semi-artificial reproduction of field eels and commercial model of raising scads according to food safety chains in Thoi Lai and Co Do districts (Khanh Trung, 2020b).	**Enterprises**: Supply seed heads and fish for commercial activities. **Laborers**: People are active in the business of eels.		

Source: *Compiled by authors*

Annex 3: Extension agents in aquaculture system in Can Tho

Organizations		Outstanding activities in the seafood industry	Results/Effectiveness of each activity	Achievements of activities
1	Can Tho university	10/2015–10/2022: Upgrading Can Tho University project (JICA, 2016)	**Import-Export partners**: Effectively implement the commitments of the SPS Agreement of the WTO by strengthening the capacity of analyzing, inspecting, and monitoring food safety in Vietnam, helping Can Tho seafood to have a higher chance of entering the export market. **Enterprises**: Increase the value of commercial seafood in the VMD, helping Can Tho seafood enterprises have abundant and quality human resources. **Laborers**: Improve student human resources through vocational training, research, exchange, training, and technology transfer to the region. **Environment**: Adapt to climate change and protect the environment (BTA, 2020).	Laboratory in High-Tech Laboratory Building (Gate B); Laboratory in the Complex (In front of the Architect); Aquatic farm (The campus after the architect); 720 new equipment for the seafood sector (CTU, 2015).
		Starting in 2020: Create a demonstration model of advanced aquaculture systems for training, research and development (CTU, 2019).	**Enterprises**: Trained and transferred technology to farms, companies, businesses, and local agencies; **Laborers**: Within the framework of the project, domestic and international students, graduate students and doctoral students at the Faculty of Fisheries are trained, practiced, and practiced annual research (CTU, 2019).	The model of super-intensive white leg shrimp farming recirculating through biological filtration in combination with other aquatic species (scale 1.5ha). The total area is 1.5 ha, including 2 recirculation systems with 12 floating pond canvas lining (400m2 each) was built in the experimental camp of Can Tho University (17 ha) (CTU, 2020).
		2017–2021: Toward sustainability in pangasius seed production: a selective approach (PANGAGEN) (CTU, 2017).	**Enterprises**: Transfer technology on aquatic genetics for breeding from Can Tho University to local facilities. Make industrial catfish more sustainable, immunize fish against bacterial disease outbreaks, and reduce the pressure of trade barriers. **Laborers**: Develop interoperability and exchange between saltwater-affected aquaculture farms and Can Tho University, meeting the needs of farming households (Nhat Linh, 2022).	Provide sustainable and comprehensive solutions to pangasius farmers facing challenges related to the increase in saltwater intrusion in the VMD by applying genetic screening (Nhat Linh, 2022).
2	Can Tho Agricultural & Fisheries Service Center	2021-2025: Can Tho City Agricultural Extension Program (My Thanh, 2021). Some programs provide information to people in Can Tho.	**Enterprises**: source of quality input seafood and labor source with knowledge and experience in the industry in each locality in Can Tho. **Laborers**: Increase value and income for people, and encourage increased production.	Support farmers to build 16 demonstration models in 5 groups of programs to apply scientific and technical advances to reduce costs and improve quality and value of agricultural products, thereby increasing economic value by 15% compared to before (Khanh Trung, 2020a). Organize the transfer and application of new scientific and technical advances to about 1,000 turns of agricultural extension officers, cooperative farmers, production farmers, etc., by direct methods and about 50,000 turns of farmers by indirect form (My Thanh, 2021). Organize 100–150 training sessions for nearly 3,500 participants with the content of applying technological advances in freshwater aquaculture and production techniques according to GAP, ASC, SQF, BMP, BAP standards (VCEA, 2022).

Source: *Compiled by authors*

Annex 4: NGOs active in the aquatic system in Can Tho

	NGOs	Technology	Training	Outcome
1	Vietnam Association of Seafood Exporters and Producers (VASEP)	2018: Businesses, cooperatives, and farming households in Can Tho City apply regulations and standards to improve product quality, such as VietGAP, GlobalGAP, ASC, BAP, etc. (VASEP, 2018a). 2019: VASEP in collaboration with Aimpharm International Co., Ltd and Nam Khoa Trading & Service Co., Ltd. held a seminar on the topic "Technical Application Multiplex Realtime PCR in microbiological testing of seafood" (VASEP, 2019). 2021: In Co Do district (Can Tho city), people take advantage of ponds and ditches, and vacant land around the house and the available water surface areas to raise a variety of freshwater aquatic species according to different models, such as intensive pond fish farming, extensive farming, and fish farming. In the fields, they raise fish in artificial tanks, fish in cages in ponds and canals and in rivers and canals (VASEP, 2021a).	2020: Traceability for seafood processing enterprises - Requirements and solutions for developing applications (VASEP.PRO, 2020). 2020: Traceability for the production and supply chain of aquatic products - Requirements and solutions for developing applications (VASEP.PRO, 2020). 2020: Guidelines for measuring, reporting and implementing energy efficiency solutions in seafood processing enterprises (VASEP.PRO, 2020). 2022: Using the realtime PCR technique to quickly detect bacteria and viruses in processing and aquaculture (VASEP.PRO, 2022b). 2022: Forum "Remove difficulties for seafood enterprises - insider's perspective" (VASEP.PRO, 2022b). 2022: Capacity building for Energy Managers in the seafood processing industry (VASEP.PRO, 2022b). 2022: Effective management of pests in seafood and food processing plants (VASEP.PRO, 2022a). 2022: Use, check and calibrate internal scales - thermometers - temperature cabinets in seafood processing factories (VASEP.PRO, 2022b).	At the end of 2017, the pangasius farming area that was certified under the standards reached 234.94 ha, accounting for 40.9% of the total pangasius farming area (574 ha), of which 224.94 ha were VietGAP and 10 ha were BAP+ ASC (VASEP, 2018a). Multiplex Realtime PCR helped to shorten the testing time to 3–8 hours, instead of 3–5 days according to the traditional method (VASEP, 2019). The area of intensive pond fish farming in the whole district reached more than 3,000 ha, while semi-intensive pond fish farming reached more than 1,300 hectares, snakehead fish farming reached more than 68,000 children, and eels raised in artificial tanks reached more than 156,000 (VASEP, 2021a).

	NGOs	Technology	Training	Outcome
2	World Wildlife Fund for Nature in Vietnam (WWF Vietnam) cooperated with Vietnam Cleaner Production Center (VNCPC)	2013–2017: Establish a sustainable pangasius supply chain in Vietnam (**SUPA**): • Adopt RAS in large pangasius farms. • Sustainable product innovation SPI: Developed and delivered 20 new products to enterprises; and some products developed from the by-products. • Training, technology transfer, with 11 courses for over 650 households in An Giang, Dong Thap, Can Tho, Vinh Long (VNCPC, n.d.).	• Workshop "Solutions to save energy, reduce production costs in seafood processing" (VNCPC, 2015). • Guidelines for sustainable consumption and production in the seafood processing in Vietnam (VNCPC, 2020). • Policy framework support through training, sharing of experience for Vietnamese consultants; comparing Vietnam policy framework in supporting development of Vietnam pangasius and seafood with the EC's (VASEP. PRO, 2017). • Promotion in Europe markets through dialogues between Vietnam (business, competent agencies) and the EU (importers); supporting enterprises activities; arranging pavilions to promote products (VASEP.PRO, 2017).	The SUPA project conducted an RECP assessment and suggested RECP options for pangasius processing factories in Can Tho. (Throughout the project's cycle, on average, each SME had already implemented 15 RECP options, in which housekeeping options that were simple and able to implement immediately account for 50%, better process control options account for 30%, and new equipment options account for 20%. On average, each company saved 18–20% of electricity, 26–30% of water, and reduced production costs from 2 to 5 billion VND per year). Develop advanced RECP techniques for hatcheries and pangasius production, and 20 advanced RECP techniques. (Increase the fertilization rate from 81% to 97% and the hatchery survival rate from 85% to 94%. Increase the survival rate and FCR for hatcheries. Increase DO using an aeration system. Increase the growth rate and reduce total phosphorus emissions into the environment by adding phytase enzyme into fish feed. Cut-off pangasius production cost. Sustainable product innovation has helped develop value-added products, constrain waste and by-products, decrease environmental impacts in pangasius processing. (Most parts of pangasius are utilized for added-value products that can serve the domestic market) (VNCPC, 2017).
		2021 - Resource Efficient and Cleaner Production (**RECP**) - Implement industrial symbiosis The project has researched and discovered 18 symbiotic solutions between enterprises, of which 7 solutions have been studied for economic and technical feasibility to propose enterprises to implement (VEM, 2021).	Industrial symbiosis focus on the following symbiotic groups: • Reuse of wastewater after treatment: Make use of wastewater in fire prevention and fighting or recover wastewater for reuse in industrial zones.- Service sharing: sharing capacity building services for workers at enterprises or providing boiler operation services; • Sharing infrastructure: sharing cold storages between companies with the same needs; • Reuse of waste: reuse iron and steel, scrap paper (VEM, 2021).	
3	International Collaborating Centre for Aquaculture and Fisheries Sustainability (ICAFIS)	2015 - Pangasius ASC certification in Vietnam. **Supported by**: WWF (ICAFIS, 2015a). 2022 - Adoption of Vietnamese Good Aricultural Practices in Small-Scale Shrimp Farming (Nguyen, Tran, and Riple, 2022).	2011 - Training auditors on the ASC pangasius standards (ICAFIS, 2011). 2015 - Training workshop on the promotion of improved on-farm shrimp feed management practices (ICAFIS, 2015b). 2016 - Training "Group Internal Auditing for Shrimp producer groups ASC standard" (ICAFIS, 2016).	Apply ASC brings technical benefits: • The survival rate of Pangasius improved (from 3% to 15%). • The quality of raw fish for processing improved with guaranteed harvest size (more uniform), stronger muscle (helps to reduce processing loss from 3% to 5%) (ICAFIS, 2015a).

Source: *Compiled by authors*

Annex 5: Policy framework supporting the implementation of mitigation in Vietnam and Can Tho

Policy framework	Objectives
Decree No. 06/2022/ND-CP on reducing GHG emissions and protecting the ozone layer (2022)	Target to minimize greenhouse gas emissions in the period up to 2030: Energy consumption in agriculture; Agricultural production; Forestry: 129,8 million tons tđ.
Decision No. 888/QD-TTg Approval for scheme setting out tasks and solutions for implementation of outcomes of the 26th conference of the parties to the United Nations framework convention on climate change (2022)	The specific objective is to promote the reduction of GHG emissions in agriculture by 43% by 2030.
Decision No. 882/QĐ-TTg National Action Plan on Green Growth for the period 2021-2030 (2022):	Formulate and implement policies, strategies, master plans, and programs on emission reduction in agriculture and rural development. Adjust and restructure aquaculture in the direction of reducing emissions. Implement the program of 100 million farmer households to reduce emissions. Policies to encourage: (1) develop organic agriculture, apply VietGAP and equivalent processes, develop a circular economy in the agricultural sector, and (3) encourage the use of water saving in agriculture and aquaculture.
Circular No. 01/2022/TT-BTNMT Detailing for implementation of the Law on Environmental Protection regarding response to climate change:	(1) Verification of GHG inventory results and GHG emissions mitigation. List, Guidelines on use, collection, transport, recycling, reuse and treatment of controlled substances.
Decision No. 2626/QĐ-BTNMT promulgating the list of emission factors for GHG inventory	(see Annex 6).
Resolution of the 13th Party Congress: Orientation to key socio-economic development targets for the five years from 2021 to 2025:	The rate of industrial parks and export processing zones in operation with centralized wastewater treatment systems meeting environmental standards is 92%; the rate of establishments causing serious environmental pollution to be treated has reached 100%.
10-Year Socio-Economic Development Strategy 2021-2030:	There has been a 9% reduction in GHG emissions compared to the development scenario with no targeted mitigation actions. In addition, 100% of production and business establishments meet environmental standards.
Decision No. 896/QĐ-TTg Approving the national strategy for climate change until 2050 (2022):	Tasks and solutions: Develop and implement an action plan to reduce methane emissions 30% by 2030 compared to 2020, and 40% by 2050 compared to 2030. Develop and implement a plan to manage and eliminate GHG and substances that deplete the ozone layer by 2050. Develop and implement plans to reduce GHG emissions by sectors, according to the roadmap to reach "zero" net emissions by 2050. Conduct a GHG inventory and reduce GHG emissions for facilities that emit 3,000 tons of CO_2eq or more annually from 2022; 2,000 tons of CO_2eq or more from 2030; 500 tons of CO_2eq or more from 2040; 200 tons of CO_2eq or more from 2050. Apply emission reduction measures in the agricultural sector through management measures, technological innovation in farming, development of low-emission agricultural value chains, and post-harvest processing and preservation. Reus crop by-products and treat livestock waste as organic fertilizer, generating biogas. Apply advanced measures in agricultural production to reduce methane emissions from livestock. Reduce post-harvest food loss and associated emissions through improved agricultural logistics and sustainable cold chain development.
Decision No. 339/QD-TTg, Approving the strategy for development of Vietnam's fisheries by 2030 with vision towards 2045:	Taking good control of waste sources from fishing, aquacultural or fish processing activities, especially fishery logistics facilities that must meet the current environmental standards. Prioritize programs and projects for implementation of the strategy for the development of Vietnam's fisheries by 2030 with a vision toward 2045 - Fishery environmental protection project. Actively control and prevent pollution in fishery production activities to protect the environment and sustainably develop the fishery sector. Investigate, evaluate and control sources of pollution and waste discharged from fisheries production activities.

Annex 6: List of emission factors for greenhouse gas inventory in the energy sector 1 – Emission sources from agriculture

	Name of greenhouse gas emission factor	Type of greenhouse gas	Value	Unit	Methods of application according to IPCC Guidelines
1	CO_2 emission factor of gasoline	CO_2	69.300	kg CO_2/TJ	Level 1
2	CH_4 emission factor of gasoline	CH_4	10	kg CH_4/TJ	Level 1
3	N_2O emission factor of gasoline	N_2O	0.6	kg N_2O/TJ	Level 1
4	CO_2 emission factor of diesel oil	CO_2	74.100	kg CO_2/TJ	Level 1
5	CH_4 emission factor of diesel oil	CH_4	10	kg CH_4/TJ	Level 1
6	N_2O emission factor of diesel oil	N_2O	0.6	kg N_2O/TJ	Level 1
7	CH_4 emission coefficient of biomass	CH_4	300	kg CH_4/TJ	Level 1
8	N_2O emission coefficient of biomass	N_2O	4	kg N_2O/TJ	Level 1

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