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# Carbon Footprint of Apostichopus japonicus Cultivation Based on Marine Bottom-sowing: A Case in Shandong Province, China

Lin Yang[a], Dong An[a], Yuhu Cui[a], Xuexiu Jia[b], Dong Yang[c,*], Mengqi Sun[c], Wensheng Li[d], Yanliang Wang[d], Longjie Wu[e]

[a]School of Business, Shandong University, Weihai 264209, China
[b]Sustainable Process Integration Laboratory-SPIL NETME Centre, Faculty of Mechanical Engineering, Brno University of Technology-VUT Brno, Technická 2896/2, 616 69, Brno, Czech Republic
[c]Institute of Science and Technology for Development of Shandong, Qilu University of Technology (Shandong Academy of Sciences), Jinan 250014, China
[d]Sea Cucumber Production Department, Mingbo Aquatic Co. LTD, Laizhou 261499, China
[e]Blue Economy Green Development Laboratory, Shandong University, Weihai 264209, China
yangdong@qlu.edu.cn

Marine aquaculture, with the potential of reducing greenhouse gas emissions and increasing carbon sink, has become an important carrier to cope with resource and environmental constraints and promote the low-carbon transformation of the global economy. This study aims to estimate the carbon footprint of fresh Apostichopus japonicus based on marine bottom-sowing cultivation technologies in the coastal area of Shandong Province, which has the main Apostichopus japonicus production in China. The aim of the study is to gain a deeper understanding of the hotspot of greenhouse gas emissions at each stage of Apostichopus japonicus production and to provide scientific and technological support for the establishment of targeted emission reduction technologies. Results showed that in the whole process of marine bottom-sowing cultivation, the growing seedling process has the highest carbon dioxide emission of 3,138.5 kg $CO_2$eq per t, accounting for 53.7 % of the total emission. The second highest carbon-emission stage is the pond cultivation process, which is 2075.0 kg $CO_2$eq per t, accounting for 35.5 % of the total emission. The reproductive process and finished Apostichopus japonicus feeding process have the lowest carbon dioxide emission, with contributions of 8.3 % and 2.5 % to the total emissions. Electricity consumption is the largest contributor to the life cycle emissions of fresh Apostichopus japonicus production based on the marine bottom-sowing.

## 1. Introduction

Excessive global greenhouse gas emission has resulted in global climate change (Hashim,2022), causing a series of serious environmental problems, such as global warming, sea level rise, frequent floods, and droughts. The ocean is a strategic place to reduce carbon emissions and increase carbon sinks, and marine aquaculture has received increasing attention from the global industry and academia due to its inherent carbon-enriching and carbon-capture negative attributes (Wang and Wang,2022). Apostichopus japonicus, which is a species of echinodermata, holothuroidea and stichopodidae, commonly known as stichopus japonicus and sea cucumber (Tu,2023). Apostichopus japonicus is an important species of mariculture in the world and is widely treated as a rare and famous seafood due to its high nutritional and economic value in the East Asia (Gao,2008). It is mainly produced in the Bohai Sea of China, the North, and South Yellow Seas on the west coast of the North Pacific Ocean, Japan, Korea, and the far eastern region of Russia (Yang,2019). Based on the FAO Statistical Database, China is the largest country of production and consumption for Apostichopus japonicus all over the world (Xu, 2015). In the past 10 y, China's production of Apostichopus japonicus has accounted for more than 97 % of the world's total production (Figure 1). Therefore, it is of great influence and significance for the

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development of the global market of Apostichopus japonicus to carry out relevant research on the cultivation of Apostichopus japonicus in China.

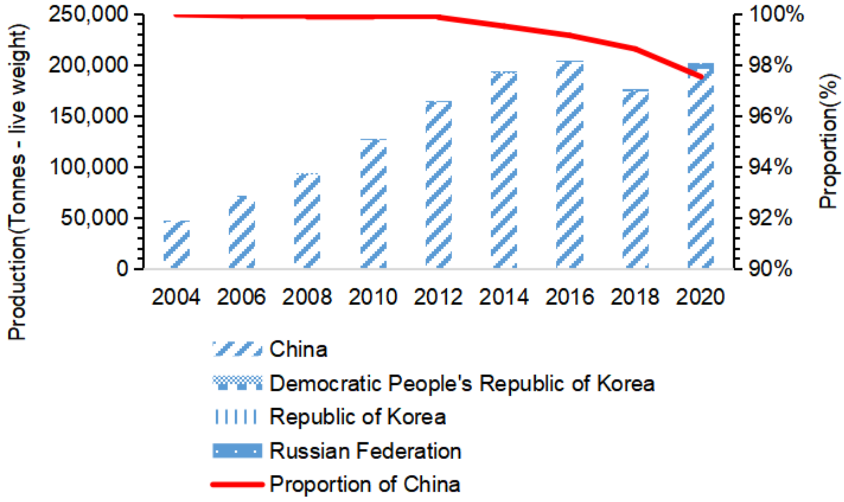


*Figure 1: Apostichopus japonicus production in China (2004-2020) Data sources: FAO Statistical Database*

Carbon footprint is the typical representative index and method based on the life cycle assessment method for assessing greenhouse gas emissions for production systems (ISO 14067). Many researchers around the world have conducted large studies on the production of different kinds of marine fisheries products in recent years. Liu (2016) compared the carbon footprint of two farming models for producing Atlantic salmon (land-based closed containment system in freshwater and open net pen in seawater), and drew a conclusion that the production of feed is the dominating climate hotspot for both production methods, energy source and transport methods are also important. Tamburini (2019) focused on the carbon footprint assessment of two seed sources for producing oysters (oyster seed purchasing from France and transport to Italy, or situ seed production), and indicated that the main hotspots were the fattening and prefattening phases of farming, which were common in both scenarios. Chang (2017) studied the carbon footprint of shrimp and concluded that the top five factors in terms of carbon emissions were as follows: electricity, feed, indirect raw materials, waste treatment and transport. Refrigerant consumption and wastewater treatment were also the key emission hotspots over the whole life cycle. Fu (2016) constructed the carbon footprint assessment of two kinds of aquaculture systems of Larimichthys crocea in Zhoushan City and concluded that the deep-water anti-wind wave aquaculture mode in deep water was better than that in deep water and diesel combustion was the emission hotspot during transportation. Sun (2022) focused on the carbon footprint assessment of kelp and indicated that breeding facilities were the main carbon source, accounting for 94 % of carbon emissions.

At present, Apostichopus japonicus mainly rely on artificial cultivation, which consumes energy and resources in the process and inevitably causes environmental impacts, such as greenhouse gas emissions and water pollution. China is implementing a strict greenhouse gas emission reduction policy to promote the green transformation of the economy and society, which also presents a new challenge to the low-carbon transformation of Apostichopus japonicus cultivation industry. However, almost no existing research on the carbon footprint of Apostichopus japonicus cultivation has been currently reported all over the world. To fill the gap, this study aims to analyze the analytical calculation of the carbon footprint of the fresh Apostichopus japonicus production based on marine bottom-sowing cultivation in China, which is the most traditional and important cultivation technology. The process data is obtained from the representative breeding and cultivation enterprises of Apostichopus japonicus production in the coastal area of Shandong Province, which accounts for the largest proportion of fresh Apostichopus japonicus production in China. By conducting the study on the carbon footprint evaluation of Apostichopus japonicus production, the study attempts to gain a deeper understanding of the hotspots of greenhouse gas emissions at each stage of Apostichopus japonicus production and provide scientific theoretical guidance for reducing greenhouse gas emissions and increasing carbon sink decision support for the promotion of low carbon development for marine aquaculture.

## 2. Materials and method

### 2.1 Goal, scope, and functional unit

The goal of this study is to evaluate the carbon footprint of fresh Apostichopus japonicus production in 2022 using the LCA method in accordance with ISO 14067. The functional unit (FU) in this study is set as the production of 1 t of fresh Apostichopus japonicus production based on the marine bottom-sowing in China.

### 2.2 System description of fresh Apostichopus japonicus production

In line with the life cycle assessment framework, the system boundary in this study was from fertilized eggs to fresh Apostichopus japonicus products (cradle to gate) (Figure 2). The reproductive process represents the hatching stage of fertilized eggs of Apostichopus japonicus, the total cultivation cycle of which is 60 - 80 days, and the size of Apostichopus japonicus seedlings reaches 0.1 g per head. The growing seedling process represents the cultivation stage in the indoor workshop pond, the nursery cycle of which is 70 - 80 days, and the size of finished Apostichopus japonicus seedlings reaches 2.5 g per head. The pond cultivation process represents the cultivation stage in the man-made ponds near the coastal mudflats, the nursery cycle of which is 70-75 days, and the size of juvenile Apostichopus japonicus reaches 10 g per head. The finished Apostichopus japonicus feeding process represents the cultivation stage from juvenile to finished Apostichopus japonicus based on marine bottom-sowing cultivation, the cultivation cycle of which is 2 - 3 y, and the size of finished Apostichopus japonicus is about 50 g per head. The auxiliary process includes the electricity used for the process of wastewater treatment. The carbon footprint of main raw materials and energy production are considered, but their production processes are not shown in Figure 2.

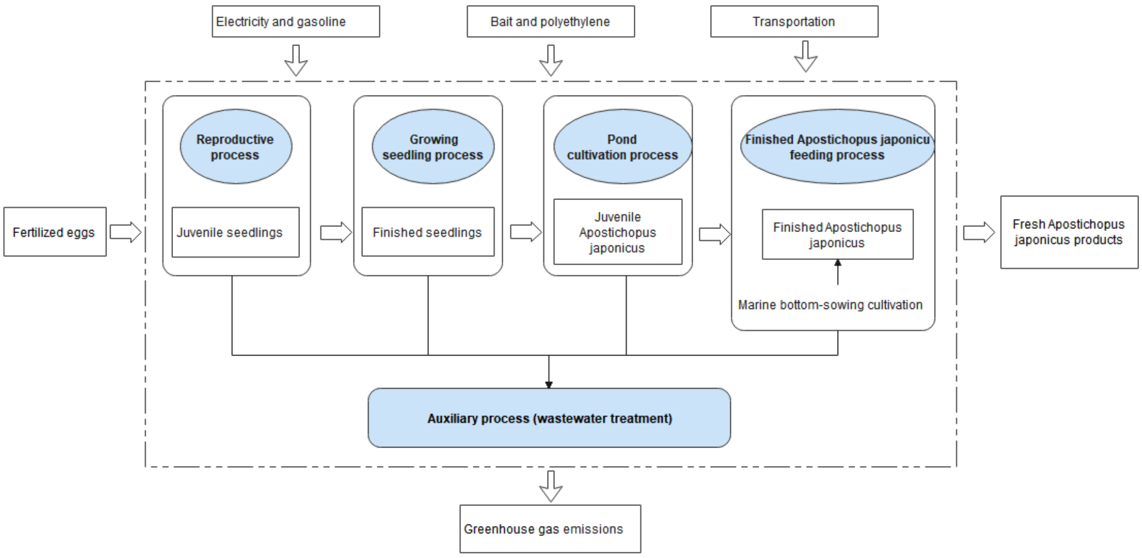


*Figure 2: System boundary of the Apostichopus japonicus cultivation based on the marine bottom-sowing*

### 2.3 Life cycle inventories

The data of this study include foreground data and background data. The foreground data mainly includes the material and resource consumption in the overall life cycle of the Apostichopus japonicus production, such as algae powder, animal protein, and electricity, during all life cycle stages. The foreground data are mainly collected from field research combined with literature research. Background data are the carbon footprint factors of the resources and energy consumption and are mainly obtained from the literature and the Ecoinvent 3.6 database. The data related to material and energy inputs and carbon emissions for the cultivation of 1 t of fresh Apostichopus japonicus products are shown in Table 1 and Table 2. Note that the data in Table 1 is obtained from field research about the representative breeding and cultivation enterprises of Apostichopus japonicus production in the coastal area of Shandong Province, China.

### 2.4 Software and LCIA method

In this study, the IPCC method (IPCC, 2013) was used for the calculation method for the carbon footprint based on the life cycle, and the Simapro 9.3 was used in this research. The carbon footprint of Apostichopus japonicus in the study area was measured from "cradle to gate" according to the requirements of the Life Cycle Assessment method. The calculation is carried out as follows.

$$CF = \sum_{i=1}^{n} V_i \times F_i \quad (1)$$

Where CF is the carbon footprint of cultured Apostichopus japonicus (kg $CO_2$eq), $V_i$ notes the first i consumption/output of a resource or energy. $F_i$ notes the emission factors of the first i resource or energy.

*Table 1: The resource and energy consumption of 1 t fresh Apostichopus japonicus production*

| Cultivation stage | Item | | Value |
|---|---|---|---|
| Reproductive process | Bait | Algae powder | 79.44 kg |
| | | Animal protein | 34.05 kg |
| | | Electricity | 33.76 kWh |
| | Electricity | | 442.67 kWh |
| Growing seedling process | Bait | Algae powder | 582.75 kg |
| | | Animal protein | 249.75 kg |
| | | Electricity | 247.63 kWh |
| | Electricity | | 2,775.00 kWh |
| | Polyethylene | | 0.24 kg |
| | Shipping transport | | 55.50 t·km |
| Pond cultivation process | Electricity | | 2,000.00 kWh |
| | Shipping transport | | 60.00 t·km |
| Finished Apostichopus japonicu feeding process | Gasoline | | 150.00 kg |
| | Shipping transport | | 25.00 t·km |
| Auxiliary process | Electricity | | 1,100 kWh |

*Table 2: The carbon footprint factors of resource and energy consumption in the fresh Apostichopus japonicus production*

| Item | Carbon emission factor | Unit | Carbon Emissions Data Sources |
|---|---|---|---|
| Algae powder | 0.027 | kg $CO_2$eq / kg | Ecoinvent 3.6 |
| Animal protein | 0.135 | kg $CO_2$eq / kg | Ecoinvent 3.6 |
| Electricity | 0.997 | kg $CO_2$eq / kWh | Sun (2021) |
| Polyethylene | 2.27 | kg $CO_2$eq / kg | Ecoinvent 3.6 |
| Shipping transport | 1.35 | kg $CO_2$eq / t·km | Ecoinvent 3.6 |
| Gasoline | 0.739 | kg $CO_2$eq / kg | Ecoinvent 3.6 |

## 3. Results analysis

### 3.1 Overall life cycle carbon footprint

As shown in Figure 3, the carbon footprint of one t fresh Apostichopus japonicus production based on the marine bottom-sowing cultivation technology is 6,936.51 kg $CO_2$eq. When comparing the greenhouse gas emissions of different stages, the most contributing process is the growing seedling process. The greenhouse gas emissions of the growing seedling process are 3,138.5 kg $CO_2$eq per t and account for 45.3 % of the carbon footprint of fresh Apostichopus japonicus production. The pond cultivation process is the second largest contributing process, has greenhouse gas emissions of 2,075.0 kg $CO_2$eq per t and occupies 29.9 % of the carbon footprint of fresh Apostichopus japonicus production. The auxiliary process is the third contribution process, has the greenhouse gas emissions of 1,096.7 kg $CO_2$eq per t and occupies 15.8 % of the carbon footprint of fresh Apostichopus japonicus production. The reproductive process is the fourth contribution process, has a greenhouse gas emissions of 481.7 kg $CO_2$eq per t and occupies 6.9 % of the carbon footprint of fresh Apostichopus japonicus production. The finished Apostichopus japonicus feeding process is the minimum contribution process, with a greenhouse gas emission of 144.6 kg $CO_2$eq per t and occupies 2.1 % of the carbon footprint of fresh Apostichopus japonicus production. Therefore, the growing seedling process and pond cultivation process are the hotspots of greenhouse gas emissions throughout all the stages of Apostichopus japonicus production.

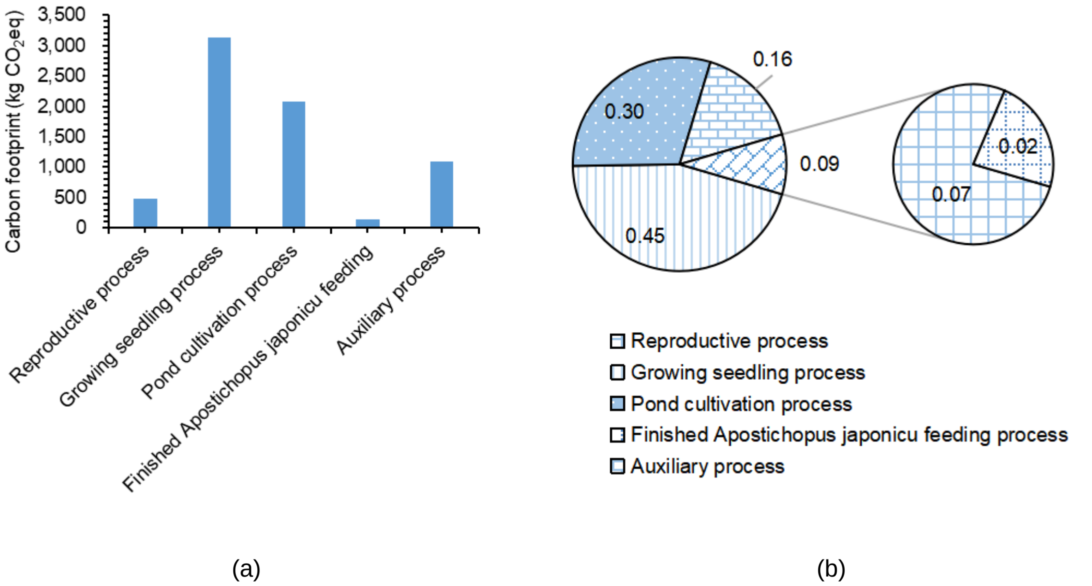


*Figure 3: Overall life cycle carbon footprint (a) and distribution (b) of the marine bottom-sowing cultivation of fresh Apostichopus japonicus production*

### *3.2* Distribution of carbon footprint

As shown in the Figure 4, it is founded that electricity consumption was the primary source of the carbon footprint of fresh Apostichopus japonicus production. A total greenhouse gas emission of 6,298.71 kg $CO_2$eq per t was generated due to the electricity consumption in the whole life cycle of Apostichopus japonicus cultivation based on the marine bottom-sowing. Among it, the greenhouse gas emissions from production processes were 5,202.01 kg $CO_2$eq per t, the rest come from the auxiliary process, which was used in wastewater treatment. For the remaining inputs, greenhouse gas emissions generated by bait consumption, shipping transportation, and gasoline consumption were 336.73 kg $CO_2$eq, 189.68 kg $CO_2$eq, and 110.85 kg $CO_2$eq per t, respectively. The main contributing inputs were also analyzed in this research according to each stage of fresh Apostichopus japonicus production. The electricity consumption and the bait for the Apostichopus japonicus were identified as the main contributors to the greenhouse gas emission in the reproductive process and growing seedling process. The main source of greenhouse gas emissions in the pond cultivation process was electricity, followed by transportation. In the finished Apostichopus japonicus feeding process, the main production process took place at sea which required the ship and related devices using gasoline. In this process, gasoline consumption is the main contributor to the greenhouse gas emission of the finished Apostichopus japonicus feeding process.

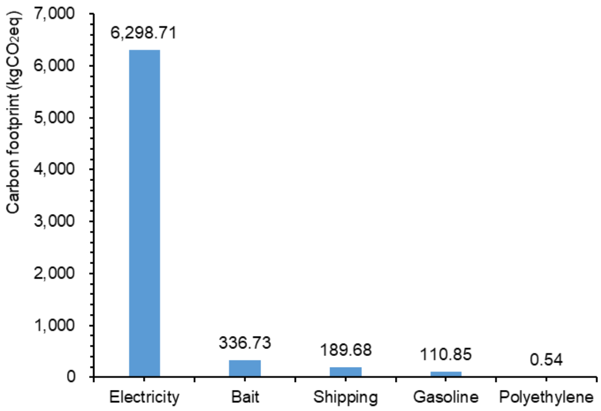


*Figure 4: Sources of the carbon footprint of 1 t of fresh Apostichopus japonicus production*

## 4. Conclusions

The overall life cycle carbon footprint of 1 t of fresh Apostichopus japonicus production with marine bottom-sowing cultivation method was analyzed in this study. It is concluded that the carbon footprint of 1t fresh Apostichopus japonicus production in China is 6,936.51 kg $CO_2$eq. The greenhouse gas emissions of different stages of fresh Apostichopus japonicus production based on marine bottom-sowing cultivation are the growing seedling process stage, pond cultivate process stage, auxiliary process, reproductive process stage and finished Apostichopus japonicus feeding process stage from high to low, which accounts for 45.3 %, 29.9 %, 15.8 %, 6.9 % and 2.1 % of the carbon footprint in the whole life cycle, respectively. The main source of greenhouse gas emissions is electricity in the whole life cycle of marine bottom-sowing cultivation of fresh Apostichopus japonicus production in China, followed by bait and shipping transport.

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