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Production-Distribution Model Considering Traceability and Carbon Emission: A Case Study of the Indonesian Canned Fish Food Industry

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Abstract: *Background:* Traceability systems and carbon emissions are two important factors involved in production and distribution activities. The involvement of these two factors in production and distribution activities along the supply chain will ensure the safety and quality of food through the manufacture, packaging and distribution of products with minimal costs and in an environmentally friendly way. *Objective*: This study aimed to develop a model of canned fish food production and distribution integration by considering traceability and carbon emissions to minimize total costs. *Method:* A mixed-integer linear programming (MILP) approach was used to develop mathematical models and the optimal solution of the model created was obtained using an open-source spreadsheet solver program. *Results:* The results show that the proposed models produce the minimum total production and distribution cost with high traceability and low carbon emissions. *Conclusions:* The sensitivity analysis from this study shows that there is a significant relationship between production, carbon emissions, and the total cost of production-distribution. Moreover, it was concluded that the production level, carbon emission level, and emission threshold can have a significant influence in the generation of the total carbon emissions.

Keywords: integration production-distribution; traceability; carbon emission; MILP

1. Introduction

The ability to integrate production and distribution to maximize profit can be done by optimizing production planning and distribution planning decisions. According to Ganji, Kazemipoor, Molana, and Sajadi [1], production-distribution integration can achieve significant profitability and a total cost reduction of 3 to 20 percent. A similar opinion was conveyed by Noroozi et al. (2018) in that the integration of production-distribution in the supply chain can maximize total profits. This is in line with the study of Aazami and Saidi-Mehrabad [2], which uses distribution-production integration planning to maximize profits. On the other hand, integrating production and distribution is a significant problem in the supply chain network [3]. This means that the decision to integrate production and distribution is very relevant because they are interrelated [4] and need to be handled together in an integrated manner [5]. However, research into distribution-production in the food supply chain has become complicated in the last few decades due to globalization and the many interactions throughout the food system [6]. This triggers undesirable factors and food safety behaviors that could lead to global food poisoning disasters [7]. According to Feng [8], a systems approach is needed to ensure food safety and quality, namely a traceability system. Several studies have reported that traceability is believed to trace and identify the source of various quality problems [9]. The same opinion was expressed by Sun and Wang [10], who stated that a traceability system is a powerful solution to overcome food safety problems. In addition, the traceability system can help minimize the production and distribution of unsafe or low-quality products [11]. For this reason, products with the best quality and safe for consumption are given more attention [12]. Moreover, food products must maintain and guarantee food safety and production process history [13].

The traceability system in the production-distribution process is fundamental because every actor in the chain has a responsibility to ensure food safety and quality through handling, manufacturing, packaging, and transporting products [14]. Several studies have examined this, such as Agustin, Mawengkang, and Mathelinea [15], who created a production-integration model in the marine product processing industry by considering the traceability system. Similarly, Yeh, Liu, Chen, Yang, and Liang [16] used a traceability system to keep fish products fresh and safe in the production-distribution process. Likewise, Chen, Chiu, Chen, Kao, and Chang [17] built a traceability information system for coordination and quality control of production, distribution, and consumption. However, to achieve profitability, companies need to integrate production-distribution by considering traceability, but it is essential to control carbon emissions [18]. This is because some carbon emissions from the entire process will come at a cost [19]. This is in line with the opinion of Aktas and Temis [20] that the production and distribution of products cause about 45% of carbon emissions. In this regard, carbon emissions have become increasingly prominent [21], and companies need to pay attention to it [22].

In recent years, reducing carbon emissions in the food supply chain has become an increasingly important issue [23] and has received attention [18]. This is because the production-distribution problem that involves multiple stages with multiple processes can produce significant carbon emissions [24]. The production of carbon emissions from production and distribution activities is expected to increase by up to thirty percent by 2050 [25]. In line with these conditions, Yang, Liu, Su, and Jing [26] and Manupati et al. [23]; accordingly stated that in 2020 various countries had committed and made unique plans to reduce carbon emissions. Meanwhile, the latest information on carbon emissions is still limited [23,27], and the amount of research is still lacking [22]. However, several researchers examining production-distribution integration considering carbon emissions, such as Palacio et al. [19] conducted a production-distribution integration study that minimized total network costs and minimized total carbon emissions (including total carbon emissions from facilities and transportation). Meanwhile, Moon et al. [24] designed a production-distribution system and tested the effect of carbon emission limits. Likewise, Aktas and Temis [20] modeled multi-product and multi-stage distribution-production networks and the value of the resulting carbon emissions. Other carbon emission research has focused more on supply chain sustainability [18,21,22]. This is because carbon emissions can affect a company's performance in a sustainable supply chain [28], which can reduce overall emissions [23]. In particular, reducing carbon emissions could slow global climate change [29].

Global climate change is related to the role of humans in protecting and maintaining environmental ecosystems. Carbon dioxide (CO_2) emissions are one of the GHG emissions resulting from the burning of fossil fuels [30]. The higher the carbon content in the fossil fuel or the lower combustion efficiency, the larger the carbon emissions. Currently, climate change is becoming more and more worrying, so governments and businesses are increasingly pressing to minimize carbon emissions. According to Sureeyatanapas et al. [29], they state that reducing carbon emissions can slow global climate change. In addition, the carbon emission index is widely used as an indicator of corporate sustainability assessment and reporting. This is because the assessment and evaluation of carbon emissions can provide an opportunity to develop supply chain sustainability [31]. Therefore, sustainability is of considerable concern for companies. Moreover, the company that considers applying the principle of sustainability can create a competitive advantage [32] and control carbon emissions [18].

According to Sarkar et al. [18], every supply chain management strategy is fundamental to reduce carbon emissions and improve quality. One way to guarantee food quality and safety is by implementing a traceability system [14,33,34]. Gallo, Accorsi, Goh, Hsiao, and Manzini [35] applied a traceability system along the supply chain to reduce carbon emissions from distribution to ensure product safety. Meanwhile, the relationship between traceability systems and carbon emissions was revealed by Muirhead and Porte [36]. They found that carbon emissions are one such case that can be reduced using a traceability system. Similar research conducted by Parashar et al. [25] identified the main supporting factors that affect the food supply chain and carbon emissions, one of the prominent supporters of the food supply chain, namely traceability. However, various traceability and carbon emission studies on production and transportation activities in the food supply chain have not been sufficiently explored. Current research tends only to consider carbon emissions, ignoring traceability, and vice versa. Meanwhile, study of traceability and carbon emissions has examined traceability as a tool to resolve the impact of carbon emission problems. Thus, there has been no research involving distribution and production activities taking account of traceability and carbon emissions simultaneously.

Some research on production-distribution integration models has considered traceability and carbon emissions studied. However, there is no research involving both production-distributions by simultaneously considering traceability and carbon emissions. Therefore, this study developed a production-distribution integration decision model by considering traceability and carbon emission in canned fish foods. The mathematical model developed in this study uses a mixed-integer linear programming (MILP) approach. The mixed-integer linear programming (MILP) method is believed to optimize mathematically [37]. Several studies, such as Agustin et al. [15], have made MILP models in production-distribution integration by considering traceability. In addition, Bilgen and Çelebi [38] presented the MILP model in solving production scheduling and distribution planning problems in a multi-product yogurt production line. Moreover, Jolayemi and Olorunniwo [39] formulated a two-stage supply chain model in determining the optimal number of products produced in each factory to be then distributed to each distribution center. Thus, this study used the MILP model simultaneously by considering traceability and carbon emissions as a differentiator from other MILP models.

This study aimed to develop a production and distribution integration model by considering traceability and carbon emissions to minimize total costs. The total costs include production, raw material purchasing, transportation, regular labor, raw material inventory, finished product inventory, distribution-inventory, production carbon emissions, shipping carbon emissions, and traceability costs. The structure of the rest of this paper comprises six sections. Section 1 (introduction) discusses the study's background and identifies the gap between previous studies and the research statement. Section 2 discusses the related studies that contributed to developing the model and approach. Subsequently, the next section develops the research model, followed by Section 4, which presents canned fish food data. Section 5 discusses the results and discussion. This is followed by the final section, which is the conclusion.

2. Literature Review

The literature review in this study was used to identify optimization methods widely used by researchers in solving production-distribution integration problems and identifying research gaps in this topic. This subsection consists of three parts, including the first section, which discusses optimization methods and meta-heuristic methods in production-distribution integration. The second part describes an optimization approach for traceability. Meanwhile, the third part concerns optimization for reducing carbon emissions. In this study, to find out which methods have been used in the distribution problem in the supply chain the Scopus database was used. Scopus was chosen because it is the largest paper indexer and more than 20,000 article abstracts are indexed on Scopus [40]. Based on the Scopus database with the keywords "production"—"distribution" and "supply chain" produced 412 papers with a research classification into two parts, namely the optimization method and the meta-heuristic method. The mathematical methods for solving production-distribution problems are non-linear programming, linear programming, mixed-integer programming, and goal programming. Meanwhile, metaheuristic methods such as genetic algorithms, simulated annealing, and particle swarm optimization can solve these problems.

2.1. Mixed Integer Programming and Optimization

Linear programming (LP) is a specific mathematical programming method in which the objective function and boundary are linear. In the production-distribution problem using the LP method, 10 out of 412 papers or 2% of the other techniques were used in the production-distribution problem. In addition, the Mixed Integer Linear Programming (MILP) method is one of the methods used in the literature with similar characteristics to the linear programming (LP) model. However, the difference is that the MILP model has linear objective functions and limits, or some decision variables are integers [41]. The MILP method can provide global optimization for each identified solution, where an integer variable is required [42]. From a total of 412 papers, 121 or 29% of the papers proposed the MILP model, so that the MILP method in this literature review is the most widely used in production-distribution problems. Meanwhile, the non-linear programming model (NLP) is a particular type of mathematical programming model with non-linear constraints and objective functions. This is because linear modeling is not applicable in most cases with complex problems. If there is an integer variable in non-linear programming, it is included in the mixed non-linear integer (MINLP). Therefore, the complexity of the non-linear and linear models encourages researchers to develop different problems. Of the 412 papers related to production-distribution in the supply chain, ten articles or 2% include one paper discussing NLP and nine papers propose the MINLP model. The goal programming method was first proposed in 1955 and which has been one of the approaches commonly used for multi-purpose decision-making problems. Currently, the goal programming method is applied to various applications, and this is because goal programming is seen as one of the most common approaches to multi-purpose planning problems [20].

2.2. Optimization Approach for the Traceability

The optimization method used in the traceability case includes mixed-integer linear and mixed-integer non-linear programming models and goal programming. The Mixed Integer Linear Programming (MILP) model is the most widely used in the literature. Some researchers who have used an optimization approach in solving traceability problems include Rong and Grunow [43]. They developed production and distribution planning to manage food safety risks in food supply chains based on traceability with the MILP approach. The same research was conducted by Agustin et al. [15]. Their study considers the traceability in planning production and distribution to meet consumer demand for product quality, using the MILP method. Likewise, Kallel and Benaissa [44] proposed the MILP model to minimize dispersed production batches to optimize traceability. Meanwhile, Thakur, Wang, and Hurburgh [45] chose mixed integer programming (MIP) because this method effectively minimizes the risk of food safety and food traceability. The same approach was conducted by Moniz, Barbosa-Póvoa, and Pinho de Sousa [46], using the MILP method in production scheduling by considering traceability. A different approach was taken by Gautam et al. [47] using a multi-objective integer non-linear programming approach by considering two objective functions, which include minimizing the total cost of logistics, the cost of implementing RFID for traceability, and the cost of contamination in the kiwifruit supply chain. Another approach used Goal Programming by considering two objective functions: minimizing the risk of failure to trace halal food that could occur during outbound logistics activities and maximizing the quality of information on halal food products [48].

2.3. Optimization Approach for Reducing Carbon Emissions

Several researchers have carried out the optimization method that has been widely used in production-distribution integration problems related to carbon emissions in Table 1. Jabarzadeh, Yamchi, Kumar, and Ghaffarinasab [49] chose a multi-objective mixed-integer linear programming method to solve an optimization model for perishable products in minimizing total network costs and carbon emissions and maximizing responsiveness to demand. Whereas Zhang, Sundaramoorthy, Grossmann, and Pinto [50] proposed an MILP model for scheduling multi-item production by considering carbon emissions in production. The MILP method was also chosen by Moon et al. [24] in formulating the problem of trade-offs between optimal profits and shortcomings in production-distribution planning with limits on carbon emissions and inaccurate information about raw material resources. On the other hand, Aktas and Temis [20] proposed a Linear Goal Programing (LGP) model to support production-distribution planning decisions by considering the value of carbon emissions generated during the transportation of materials and products.

The literature review we conducted shows that MILP has been widely proposed for production-distribution problems related to traceability and carbon emissions. However, the MILP method for combining both traceability and carbon emissions in production-distribution problems has not been discussed. Therefore, this study proposes the MILP method by considering traceability and carbon emissions simultaneously.

Table 1. Comparison of models related to the proposed research topics.

Authors	Traceability	Carbon Emission	Solution Approach
Rong & Grunow [43]	Traceability	No	Mixed-integer linear programming
Agustin et al. [15]	Traceability	No	Mixed-integer linear programming
Kallel & Benaissa [44]	Traceability	No	Mixed integer linear programming
Maitri Thakur et al. [45]	Traceability	No	Mixed-integer programming
Moniz et al. [46]	Traceability	No	Mixed-integer linear programming
Gautam et al. [47]	Traceability	No	Multi-objective integer non-linear programming
Usman et al. [48]	Traceability	No	Goal Programming
Jabarzadeh et al. [49]	No	Carbon emission	MILP
Zhang et al. [50]	No	Carbon emission	MILP
Moon et al. [24]	No	Carbon emission	MILP
Aktas & Temis [20]	No	Carbon emission	Linear Goal Programming
Proposed model	Traceability	Carbon emission	MILP

In reducing carbon emissions, the government and industry have issued several strategies, namely: carbon tax (CT), carbon cap (CC), strict carbon capping (SCC), carbon cap-and-trade (CCT). Benjafaar et al. [30] defined some of these strategies, namely: the "carbon tax" strategy or "carbon tax" is a strategy for companies. Meanwhile, the "carbon cap" means that market participants may be given an obligation to reduce/limit carbon emissions. Generally, a stamp is applied to allocate emissions allowances at the beginning of the period. Participants who exceed their cap can purchase additional quota from participants whose quota is not used. From these data, it can be seen whether the emission is in excess or not. This data will also be used as a basis for determining emission limits in the next period [51]. The continuation of this strategy is called the "carbon cap-and-trade" or "limit-and-trade" strategy, which is a strategy that is charged with limiting carbon emissions to the parties involved. Several studies related to carbon emission reduction and restriction policies are detailed in Table 2.

Table 2. Carbon emission reduction studies in production and distribution.

Authors	Emission Source				Carbon Emission		Sustainability	
	CT	SCC	CCT	CC	Production	Distribution	Focus	Investment
Mishra et al. [52]	√	-	-	-	√	NA	Sustainable economic production quantity	green technology
Ahmed and Shakar [53]	√	-	-	√	√	√	Sustainable supply chain	NA
Manupati et al. [23]	√	√	√	-	√	√	Sustainable supply chain	NA
Ahmed and Shakar [54]	√	-	-	-	√	√	Sustainable supply chain	NA
Li et al. [55]	-	-	√	-	√	NA	Sustainable supply chain	green technology
Rosic and Werner [56]	√	-	√	-	NA	√	Economic & Environmental	NA
Bouchery et al. [57]	√	-	-	√	NA	NA	Stainability performance	NA

3. Model Development

This research used a mathematical model with attention to traceability and carbon emissions at the stage of developing the proposed model. Furthermore, the mathematical model of the integrated production-distribution network was formulated into a mathematical model using a mixed-integer programming approach. At the model testing stage, numerical testing is carried out based on one real case example in the marine product processing industry. Analysis of model testing was carried out to provide an overview of the performance and evaluation of the proposed model. After testing the model analysis with data in real cases, a sensitivity analysis test is then carried out. Sensitivity analysis is needed to see how much the model performance changes with changes in model parameters.

3.1. Production-Distribution Integration: Canned Fish Foods Networks

The marine product processing industry is the most reliable sector in Indonesia's national economy [58]. One of the food products that use basic raw materials for marine fish is the fish canning industry [59]. Canned fish products are one example of how seafood products are served [60]. According to [61] canned fish food is in demand by consumers worldwide because it can be stored for a long time, is ready for consumption, and is affordable. It can also maintain nutritional value and food safety without additives or preservatives [62]. This is why the demand for canned fish products has increased since 1960 [63]. The same thing was stated by Hospido et al. [60]; Avadí et al. [64] said that canned fish products are in great demand, and the demand will continue to increase in the next decade. Likewise, Pecoraro et al. [65] emphasized that the demand for seafood processing is internationally increasing; this encourages companies in the fish canning sector to increase capacity utilization, improve operational efficiency, and maximize profitability [66].

In this article, the case study taken was in the fish canning industry. Figure 1 shows a fish canning production system starting from several raw fish supplies, namely $m = 1, 2, \ldots M$, and sent to the plant as much as $j = 1, 2, \ldots J$, followed by material processing. Raw fish materials in the factory will be stored in the raw material inventory system. The factory will then produce several kinds of processed canned fish as much as $p = 1, 2, \ldots P$. In producing canned fish, it takes several W workers, which represents the labor in producing canned fish products. In addition, carbon emissions with ELV limits are carbon emissions produced according to permits from the government. After manufacturing processes, the canned fish products are sent to the distributor center as much as $l = 1, 2, \ldots L$. During the distribution process, transportation carbon emissions can arise during the shipping process. The canned fish products can then be sold by retailers with a demand pattern from the end customer.

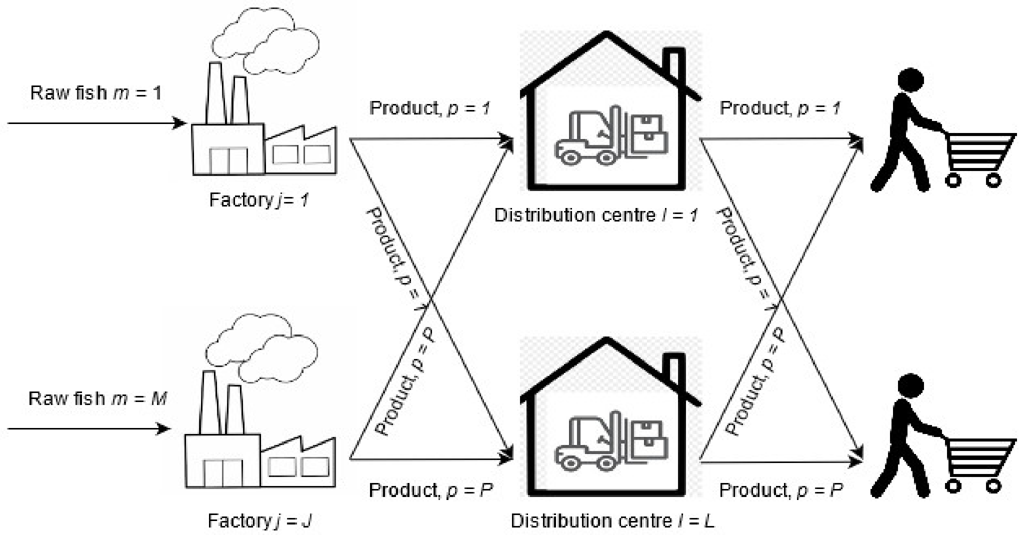

Figure 1. Production-distribution network for canned fish products.

Figure 1 shows the production-distribution network for a canned fish product. The integrated production and distribution network of Figure 1 can be formulated into a mathematical model using the mixed-integer programming approach.

3.2. Indices

- Time period with index t, $t = 1, 2, \ldots T$
- Canned fish products with index p, $p = 1, 2, \ldots P$
- Factories with index j, $j = 1, 2, \ldots J$
- Raw fish material with index m, $m = 1, 2, \ldots M$
- Central distributor with index l, $l = 1, 2, \ldots L$

3.3. Parameter

- D_{lj}^{t}: demand for product p at distributor center l in period t (kg)
- P_{pj}^{t}: production rate for product p at factory j in period t (kg)
- CP_{pj}^{t}: production costs to produce p at factory j in period t (US$/kg)
- CR_{mj}^{t}: cost of purchasing raw fish material m for factory j in period t (US$/kg)
- CT_{plj}^{t}: transportation costs for delivering canned fish product p from factory j to distributor center l in period t (US$/kg)
- CW_{j}^{t}: costs associated with workers in factory j in period t (US$/person)
- CIR_{mj}^{t}: inventory cost of raw fish material m in factory j in period t (US$/kg)
- CIP_{pj}^{t}: inventory cost of canned fish product p at factory j in period t (US$/kg)
- CID_{pl}^{t}: inventory cost of canned fish product p at distributor center l in period t (US$/kg)
- CEP_{pj}^{t}: cost of carbon emissions in producing canned fish p at mill j in period t (US$/kg-$CO_2$)
- CET_{lj}^{t}: cost of carbon emissions in transporting canned fish products from factory j to distributor center l in period t (US$/kg-$CO_2$)
- CTF_{pj}^{t}: tracing cost of canned fish product p at factory j in period t (US$/kg)
- ELV: total government allowable carbon emissions (kg-CO_2)
- W: availability of labor in producing canned fish products (people)

- EP^t_{pj}: emission rate of production for producing canned fish p at factory j in period t (kg-CO_2/kg)
- ET^t_{lj}: transport emission rate for delivering canned fish product p at distributor center l in period t (kg-CO_2/kg)

3.4. Decision Variables

- x^t_{pj}: total production of canned fish product p in factory j in period t (kg)
- u^t_{mj}: quantity of raw fish m supplied to factory j in period t (kg)
- z^t_{plj}: quantity of canned fish products p shipped from factory j to distributor center l in period t (kg)
- w^t_j: number of workers required in period t (people)
- IR^t_{mj}: level of raw fish stock m in factory j in period t (kg)
- IP^t_{pj}: stock level of canned fish products p at factory j in period t (kg)
- ID^t_{pl}: stock level of canned fish products p at distributor center l in period t (kg)
- TEP^t_{pj}: total production emissions from canned fish production p at factory j in period t (kg-CO_2), $TEP^t_{pj} = x^t_{pj} \cdot EP^t_{pj}$
- TET^t_{lj}: total transport emissions from plant j to distributor center l in period t (kg-CO_2), $TET^t_{lj} = \sum_{p \epsilon P} z^t_{plj} \cdot ET^t_{lj}$
- y^t_{pj}: binary variable, which states that if 1, then production and trace are carried out, and if 0, then vice versa in plant j at period t.

3.5. Mathematical Model

The problem shown in Figure 1 can be formulated to minimize total costs. The costs associated with production costs are, raw fish purchase costs, canned fish product distribution costs, labor costs, storage costs for raw fish materials, storage costs for canned fish products in factories, storage costs, canned fish products in the distributor center, production carbon emissions costs, transportation carbon emissions costs, tracing costs of canned fish products. The equations of the total cost (TC) can be formulated as follows:

$$
\begin{aligned}
\text{Minimize } TC = \; & \sum_{p\epsilon P} \sum_{j\epsilon J} \sum_{t\epsilon T} CP^t_{pj} x^t_{pj} + \sum_{m\epsilon M} \sum_{j\epsilon J} \sum_{t\epsilon T} CR^t_{mj} u^t_{mj} \\
& + \sum_{p\epsilon P} \sum_{l\epsilon L} \sum_{j\epsilon J} \sum_{t\epsilon T} CT^t_{plj} z^t_{plj} + \sum_{j\epsilon J} \sum_{t\epsilon T} CW^t_j w^t_j \\
& + \sum_{m\epsilon M} \sum_{j\epsilon J} \sum_{t\epsilon T} CIR^t_{mj} IR^t_{mj} + \sum_{p\epsilon P} \sum_{j\epsilon J} \sum_{t\epsilon T} CIP^t_{pj} IP^t_{pj} \\
& + \sum_{p\epsilon P} \sum_{l\epsilon L} \sum_{t\epsilon T} CID^t_{pl} ID^t_{pl} + \sum_{p\epsilon P} \sum_{j\epsilon J} \sum_{t\epsilon T} CEP^t_{pj} TEP^t_{pj} \\
& + \sum_{l\epsilon L} \sum_{j\epsilon J} \sum_{t\epsilon T} CET^t_{lj} TET^t_{lj} + \sum_{p\epsilon P} \sum_{j\epsilon J} \sum_{t\epsilon T} CTF^t_{pj} x^t_{pj}
\end{aligned} \tag{1}
$$

To minimize the objective function in Equation (1) there are several constraints which are formulated as follows:

$$\sum_{j\epsilon J} x^t_{pj} \leq \sum_{j\epsilon J} u^t_{mj} \tag{2}$$

$$x^t_{pj} \leq y^t_{pj} P^t_{pj} \tag{3}$$

$$\sum_{l\epsilon L} z^t_{plj} \leq x^t_{pj} \tag{4}$$

$$IR^t_{mj} = IR^{t-1}_{mj} + u^t_{mj} - \sum_{p\epsilon P} x^t_{pj} \tag{5}$$

$$IP^t_{pj} = IP^{t-1}_{pj} + x^t_{pj} - \sum_{l\epsilon L} z^t_{plj} \tag{6}$$

$$ID_{pl}^{t} = ID_{pl}^{t-1} + \sum_{j\epsilon J} z_{plj}^{t} - D_{pl}^{t} \tag{7}$$

$$IP_{pj}^{t} + x_{pj}^{t} \geq \sum_{l\epsilon L} z_{plj}^{t} \tag{8}$$

$$ID_{pl}^{t} + \sum_{j\epsilon J} z_{plj}^{t} \geq D_{pl}^{t} \tag{9}$$

$$\sum_{p\epsilon P}\sum_{j\epsilon J}\sum_{t\epsilon T} x_{pj}^{t} EP_{pj}^{t} + \sum_{p\epsilon P}\sum_{l\epsilon L}\sum_{j\epsilon J}\sum_{t\epsilon T} z_{plj}^{t} ET_{lj}^{t} = ELV \tag{10}$$

$$\sum_{j\epsilon J}\sum_{t\epsilon T} w_{j}^{t} = W \tag{11}$$

Constraints (2)–(4) represent the amount of raw fish supply supplied and produced into canned fish product p, which must have the same production rate (production capacity) in period t at factory j. Constraints (5) to (7) represent the supply of raw fish and canned fish products in factory j, and also the supply at distributor center l in period t must be balanced. Constraints (8) to (9) ensure that the production and deliveries from each factory must be equal to market demand. Constraint (10) ensures that the total production emission level and transportation emission level must be equal to the allowable emission limit value. Constraint (11) ensures that the number of workers is equal to the number of workers available.

4. Canned Fish Food Data

This research was conducted in the seafood processing industry from January to February 2021. The system's flow starts from the historical data on demand from end customers to distributors, where distributors recap demand data and make demand forecasts. The results of demand forecasting are used as a reference for carrying out the production process. Carbon emissions will be produced during the production processes. Then after the production process is carried out, the product will be sent to the distributor center. Then the product will be sent to the retailer. The process of shipping will produce carbon emissions.

In the case study, two fish canning factories are operating, namely j_1 and j_2. These two factories produce two types of canned fish products, p_1 and $p_{2,}$ with the need for raw materials, m_1 and $m_{2,}$ in the t_1 period with the demand as shown in Table 3.

Table 3. The production rate for products p at factory j in period t.

Raw Fish (*M*)	Factory (*J*)	Product (*P*)	Period (*T*) (kg)		Total (kg)
			1	2	
m_1	j_1	p_1	45,000	35,000	80,000
		p_2	45,000	30,000	75,000
	j_2	p_1	45,000	45,000	90,000
		p_2	35,000	35,000	70,000
m_2	j_1	p_1	45,000	35,000	80,000
		p_2	45,000	30,000	75,000
	j_2	p_1	30,000	45,000	75,000
		p_2	35,000	35,000	70,000
	Total		170,000	145,000	315,000

In the case study, the company operates two types of fish cannery, namely j_1 and j_2 which will produce two types of canned fish products, p_1 and p_2 with the need for raw material types, m_1 and m_2 in the t_1 period with a consecutive amount of 45,000 kg, 45,000 kg, 45,000 kg, 35,000 kg, 45,000 kg, 45,000 kg, 30,000 kg, 35,000 kg and for the t_2

period, with consecutive amounts of 35,000 kg, 30,000 kg, 45,000, 35,000 kg, 45,000 kg, 45,000 kg, 30,000 kg, 35,000 kg. The data on demand for p_1 and p_2 canned fish products for each distributor center, $l_{1,}$ and l_2 in the t_1 period amounted to 3000 kg, 3000 kg, 3000 kg, and 3000 kg respectively, while in the t_2 period, with a successive demand of 8000 kg, 8000 kg, 8000 kg and 8000 kg. In addition to production and demand data, production costs for factories j_1 and j_2 producing canned fish products, p_1 and p_2 are shown in Table 4.

Table 4. Production cost with producing *p* canned fish products at factory *j* in the period *t*.

Factory (*J*)	Product (*P*)	Period (*T*) (US$/kg)		Total (US$/kg)
		1	2	
j_1	p_1	200	200	400
	p_2	150	150	300
j_2	p_1	300	300	600
	p_2	230	230	460
Total		880	880	1760

Moreover, the cost of purchasing raw fish materials, m_1 and m$_2$ for each factory j_1 and j_2, namely in the t_1 period, respectively US$150/kg, US$250/kg, US$175/kg, and US$200/kg, while the cost of purchasing raw fish at t_2 periods are US$150/kg, US$250/kg, US$175/kg, and US$200/kg. The transportation costs from factories j_1 and j_2 to distribution centers l_1 and l_2 are also provided in sending canned fish products, p_1 and p_2, in the t_1 period can be seen in Table 5.

Table 5. Distribution cost to deliver canned fish products *p* from factory *j* to DC *l* in the period *t*.

Factory (*J*)	Distribution Center (*L*)	Product (*P*)	Period (*T*) (US$/kg/Trip)		Total (US$/kg/Trip)
			1	2	
j_1	l_1	p_1	250	350	600
		p_2	250	300	550
	l_2	p_1	250	300	550
		p_2	250	200	450
j_2	l_1	p_1	225	250	475
		p_2	225	250	475
	l_2	p_1	225	250	475
		p_2	225	250	475
Total			1900	2150	4050

In addition, the labor costs for factories j_1 and j_2 were also obtained, namely US$40/person. It is also known that the data on the cost of raw fish stock, m_1 and m_2 stored at factories j_1 and j_2 for each period t_1 are US$2/kg, US$1.5/kg, US$1/kg, and US$2/kg. Meanwhile, in period t_2 it is US$2/kg, US$1.5/kg, US$1/kg, and US$3/kg. The inventory costs for canned fish products, p_1 and p_2 stored in factories j_1 and j_2 for each period t_1 are US$2/kg, US$3.2/kg, US$2.2/kg, and US$2.5/kg while in period t_2 they are US$2.5/kg, US$4/kg, US$3.2/kg, and US$3.6/kg. Then, the inventory costs for canned fish products, p_1 and p_2 stored at each distributor center l_1 and l_2 for each period t_1 are US$14.6/kg, US$14.4/kg, US$14.5/kg, and US$14.8/kg, while in the period t_2 is $ 14.7/kg, US$14.5/kg, US$14.3/kg and US$14.2/kg.

Another data collection is carbon emission data. Carbon emission data is divided into two, namely production carbon emission and distribution carbon emission data. The following is the production carbon emission data for factory j_1 and j_2 to produce canned fish products, p_1 and p_2 in the period t_1 are shown in Table 6.

Table 6. The carbon emission cost to produce canned fish products p at factory j in the period t.

Factory (J)	Product (P)	Period (T) (US$/kg-$CO_2$)		Total (US$/kg-$CO_2$)
		1	2	
j_1	p_1	1.5	1.5	3.0
	p_2	1.4	1.4	2.8
j_2	p_1	1.4	1.4	2.8
	p_2	1.5	1.5	3.0
Total		5.8	5.8	11.6

Meanwhile, transportation carbon emission data that sends canned fish products, p_1 and p_2 to distributor centers l_1 and l_2 in the t_1 period are US$2/kg-$CO_2$, US$2/kg-CO_2, US$1/kg-$CO_2$, and US$1.8/kg-CO_2 and in period t_2 are US$2.2/kg-$CO_2$, US$2/kg-CO_2, US$1/kg-$CO_2$, and US$1.8/kg-CO_2. Then carbon emission data is also divided into two parts: production carbon emission data and transportation carbon emission data. The following is the production carbon emission data for plants j_1 and j_2 to produce canned fish products, p_1 and p$_2$ period t_1, namely US$1.5/kg-$CO_2$, US$1.4/kg-CO_2, US$1.4/kg-$CO_2$, and US$1.5/kg-CO_2 and in period t_2 are US$1.5/kg-$CO_2$, US$1.4/kg-CO_2, US$1.4/kg-$CO_2$, and US$1.5/kg-CO_2. Meanwhile, the production carbon emissions data in the t_1 and t_2 periods were 0.05 kg-CO_2/kg for all j_1 and j_2 factories and produced all canned fish products, p_1 and p_2. Carbon emission of distribution in period t_1 and t_2 are 0.005 kg-CO_2/kg for all shipments to distributor centers l_1 and l_2 for canned fish products, p_1 and p_2. In addition, it is also known that the carbon emission threshold value (E), which is 15,000 kg-CO_2 for all activities, both production, and transportation, is also known for the availability of 250 workers.

5. Results and Discussion

From the calculation with the Solver software, the total cost is US$252,361,498. Table 7 shows the entire cost component with the amount that forms the total cost. From these components, it can be seen that the cost of storing raw fish materials and the cost of storing canned fish products at the factory is US$0, which means that there is no inventory of these two types of materials and products in the factory. The highest cost composition is the purchase cost component, which is 48.23%. Table 7 also concludes that the cost of carbon emissions is minimal, at 0.01%. This is because the cost of carbon emissions for each product is lower than the component cost of purchasing raw materials.

Table 7. Cost calculation results.

Cost Component	Amount (US$)	Percentage
Production cost	57,668,182	22.85%
The cost of purchasing raw fish	121,704,545	48.23%
Canned fish product distribution costs	67,488,636	26.74%
Labor cost	10,000	0.00%
The cost of storing raw fish ingredients	0	0.00%
The cost of storing canned fish products at the factory	0	0.00%
The cost of storing canned fish products at the distributor center	4,977,582	1.97%
The cost of carbon emissions from production	19,841	0.01%
The cost of carbon emissions from distribution	1984	0.00%
Tracing costs of canned fish products	490,727	0.19%
Total cost	**252,361,498**	**100.00%**

The optimal results on the amount of raw fish supply, the amount of production, the number of products sent to distributors, the number of workers, the number of carbon emissions can be seen in Tables 8–13 and Figures 2–6.

Table 8. The total raw fish supply.

Raw Fish (M)	Factory (J)	Period (T)(kg)	
		1	2
m_1	j_1	90,000	65,000
	j_2	47,727	80,000
m_2	j_1	37,727	65,000
	j_2	162,727	80,000

Table 9. The total production.

Factory (J)	Product (P)	Period (T) (kg)	
		1	2
j_1	p_1	45,000	35,000
	p_2	45,000	30,000
j_2	p_1	2727	45,000
	p_2	35,000	35,000

Table 10. Number of products delivered from factory to distribution center.

Factory (J)	Distribution Centre (L)	Product (P)	Period (T) (kg)	
			1	2
j_1	l_1	p_1	42,273	0
		p_2	10,000	0
	l_2	p_1	2727	35,000
		p_2	35,000	30,000
j_2	l_1	p_1	0	10,000
		p_2	0	5000
	l_2	p_1	2727	35,000
		p_2	35,000	30,000

Table 11. Amount of labor.

Factory (J)	Period (T) (Person)	
	1	2
j_1	62	63
j_2	62	63

Table 12. Total carbon emissions from production.

Factory (J)	Product (P)	Period(T) (kg-CO_2)	
		1	2
j_1	p_1	2250	1750
	p_2	2250	1500
j_2	p_1	136	2250
	p_2	1750	1750

Table 13. Total carbon emissions of distribution from factory to distribution center.

Distribution Centre (*L*)	Product (*P*)	Period (*T*) (kg-CO_2)	
		1	2
l_1	p_1	225	175
	p_2	225	150
l_2	p_1	14	225
	p_2	175	175

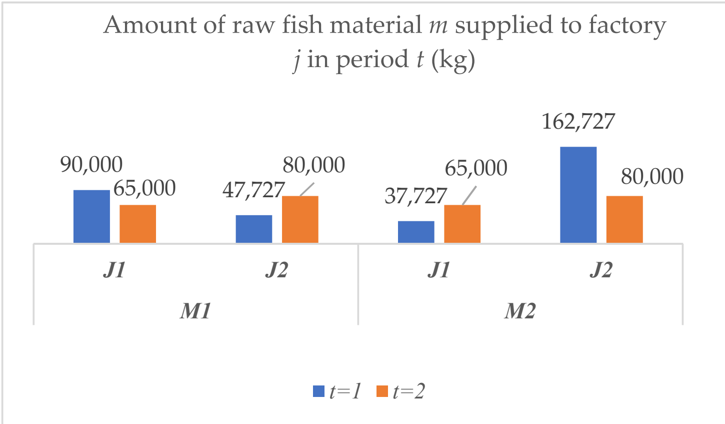

Figure 2. The total raw fish supply.

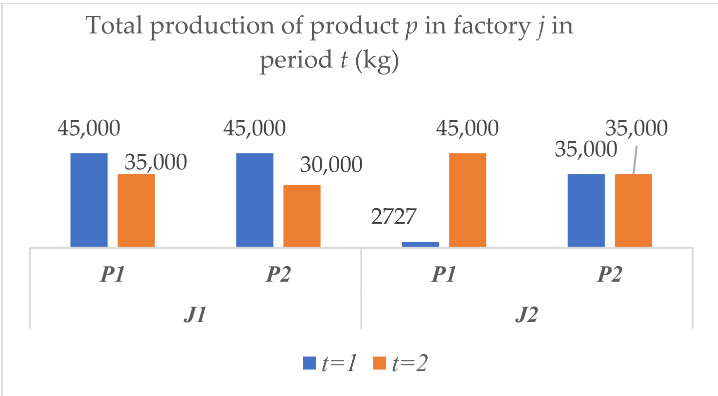

Figure 3. The total production.

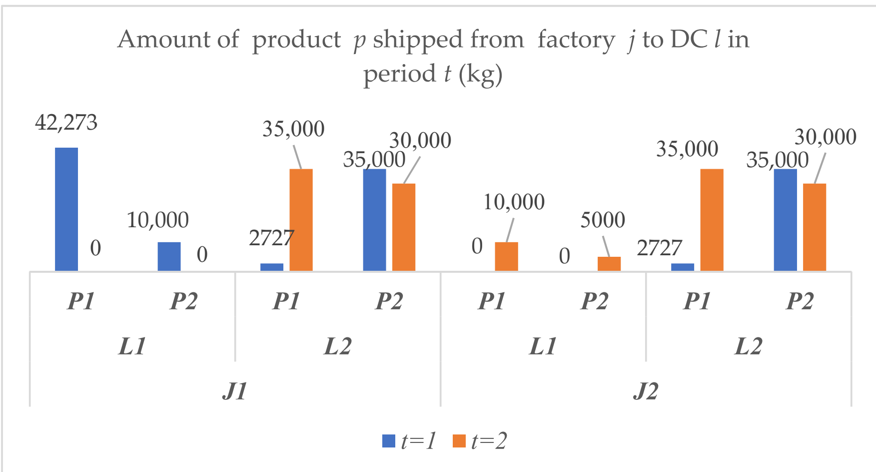

Figure 4. Amount of product supply to the distribution centers.

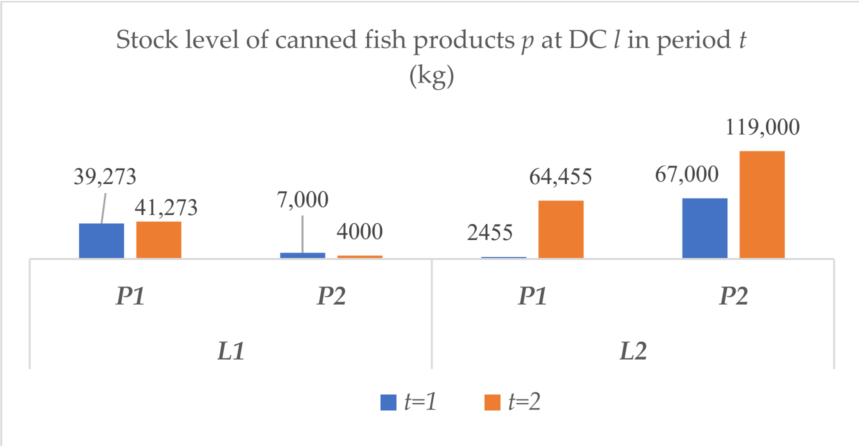

Figure 5. The total inventory of products at the distribution centers.

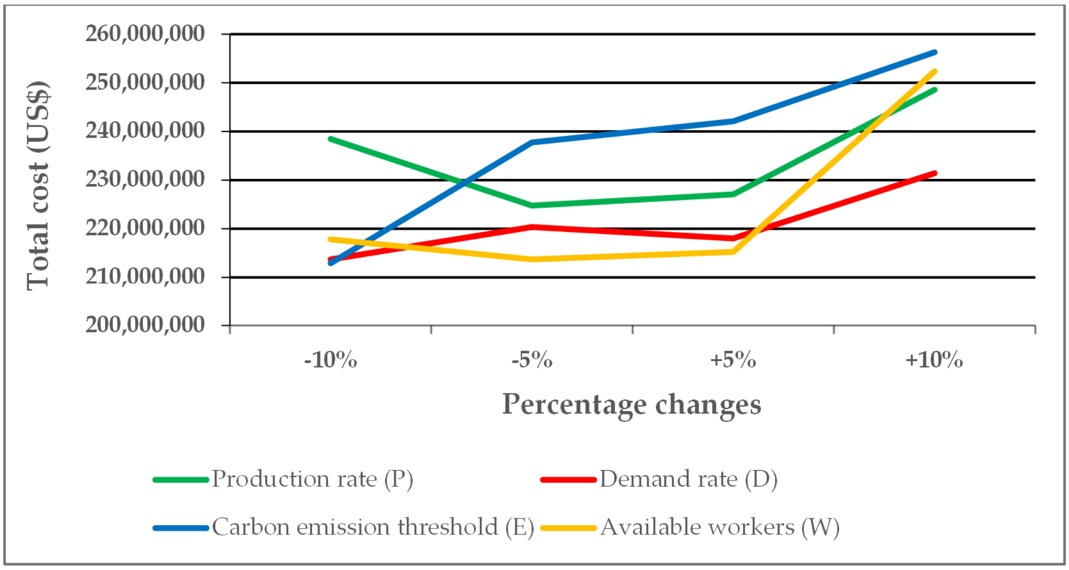

Figure 6. Sensitivity level of production level, demand level, carbon emission threshold value, and available workers to total cost.

The amount of raw fish material (m) supplied to factory (j) in period (t) can be seen in Figure 2. It shows that the supply of the second type of raw fish material (m_2) reaches the most significant number for the second factory (J_2) in the first period (t_1). Moreover, the second product type (P_2) is the most produced by the factories compared to other product types (see Figure 3).

In the perspective of distribution, the results indicate that the first factory (j_1) delivered a higher number of both products to distribution center 1 (l_1) in the first period (t_1) (see Figure 4). Meanwhile, Figure 5 shows that the stock level for product 2 (p_2) in distribution center 2 (l_2) is higher than product 1 in distribution center 1 (l_1).

This study resulted in total carbon emission in the production process being greater than the total distribution of carbon emissions. The amount of carbon emission generated in distribution activities is 1364 kg-CO_2 (9.04%). At the same time, the amount of carbon emission in the production process is 13,636 kg-CO_2 (90.91%). This is in line with the opinion of Wang, Zhang, Hou, and Yao [67], which states that carbon emissions generated in distribution are significantly lower. In contrast to Aktas and Temis [20], carbon emissions resulting from production and distribution activities are 45%. According to (Parashar et al. [25], food-related products are likely to cause emissions during production and distribution. The same result was conveyed by Phatak [68] in his research which states that carbon emissions occur in various stages of food processing that involve machines in the production system [69]. In addition, according to Aktas and Temis [20] and Saga, Jauhari, Laksono, and Dwicahyani [70], the increase in the number of products causes a significantly greater amount of production, which can trigger large carbon emissions. This statement is supported by the facts shown in Tables 7 and 10. The increased production rates affect the cost of carbon emissions [71], but the number of goods sent will affect the distribution of carbon emissions [72]. This can be seen in Table 8, representing the number of products sent from the factory to the distributor center. Meanwhile, Table 11 amounts to the total distribution of carbon emissions from the factory to the distributor center. Thus, an increase in the amount of production will significantly affect the cost of carbon emissions.

Table 1 shows the cost of production level carbon emissions of 0.01% of the total cost with distribution costs of 0.00%. This means that the costs incurred for production of carbon emissions are US$19,841 of the total cost of US$252,361,498. Meanwhile, the cost of distribution carbon emissions was US$1984, which is 10% of the cost of producing carbon emissions. Unit distribution of carbon emission costs is obtained for each item shipped from the manufacturing unit to the distribution center. In addition, the costs considered in the study, apart from the cost of carbon emissions, were traceability costs of US$490,727 or 0.19%, being much higher than the cost of carbon emissions (US$19,841). The traceability cost is influenced by the number of products multiplied by the traceability costs. Traceability costs include tracing costs that include food movement through certain production, processing, and distribution stages. In this case, the definition of traceability is the actions of tracking and following food raw materials and products through the stages of production, inventory, and distribution. The definition of traceability in this study follows the principles of the traceability system of Ramesh & Jarke [73]. They believed that a successful traceability system is a combination of planning stages, determining when-how-where-why each traceability link is created.

5.1. Sensitivity Analysis

Sensitivity analysis was carried out to test the robustness of the proposed model's results, meaning that a sensitivity analysis of several parameters carries out the model testing. The parameters carried out by the sensitivity analysis are the level of production from the factory, the level of demand, the carbon emission threshold value, and the available workers. This analysis was carried out by looking at how much influence a parameter changes the outcome of the decision. The rate of change in sensitivity was −10%, −5%, +5%, and +10%. The results of the sensitivity analysis are shown in Table 13 and Figure 6. In Table 14, the cost saving is calculated using the following formula:

$$\%\text{Saving} = \frac{\text{Total innitial } \cos\text{ts} - \text{Total changed } \cos\text{ts})}{\text{Total innitial } \cos\text{ts}} \times 100\% \tag{12}$$

Table 14. Sensitivity analysis of parameter changes to the total cost.

Parameter	Sensitivity	Parameter Changes				
		−10%	−5%	0%	+5%	+10%
Production rate	Total cost (US$)	238,466,178	224,758,029	252,361,498	227,063,487	248,564,129
	Saving (%)	5.51	10.94	0.00	10.02	1.50
Demand rate	Total cost (US$)	213,691,859	220,349,054	252,361,498	218,018,360	231,403,106
	Saving (%)	15.32	12.69	0.00	13.61	8.30
Emission threshold value	Total cost (US$)	212,893,911	237,748,252	252,361,498	242,100,928	256,273,970
	Saving (%)	15.64	5.79	0.00	4.07	−1.55
Available worker	Total cost (US$)	217,829,836	213,684,594	252,361,498	215,242,879	252,362,498
	Saving (%)	13.68	15.33	0.00	14.71	0.00

Figure 6 shows that the carbon emission limit parameters and the production level are extremely sensitive to the total cost. Meanwhile, the parameters of the availability of workers and the demand level have changed but are not significant for the total cost. Meanwhile, the relationship between the four other parameters to total carbon emissions (kg-CO_2) can be seen in Figure 7. Figures 8 and 9 shows the impact of carbon emissions from production at each j_1 and j_2 plant and transportation at each distributor center l_1 and l_2.

The parameters used in conducting the sensitivity analysis are similar to other studies, such as production parameters, demand, and carbon emission thresholds. Mishra, Wu, and Sarkar [52] developed a sustainable economic production quantity model using demand parameters and carbon emissions limits. Likewise, Moon et al. [24] included the demand parameters and carbon emission limits in the bi-objective optimization problem model with mixed-integer linear programming. These two parameters have been used for the development of mathematical models by other researchers such as Saga et al. [70], Manupati et al. [23], Jauhari [71], and Mishra et al. [52]. Meanwhile, Sarkar et al. [72] used production and demand level parameters in developing a model in a three-echelon supply chain. Furthermore, Sarkar et al. [18] also paid attention to production level parameters and demand for sustainable supply chain management with a single-setup-multi-delivery policy.

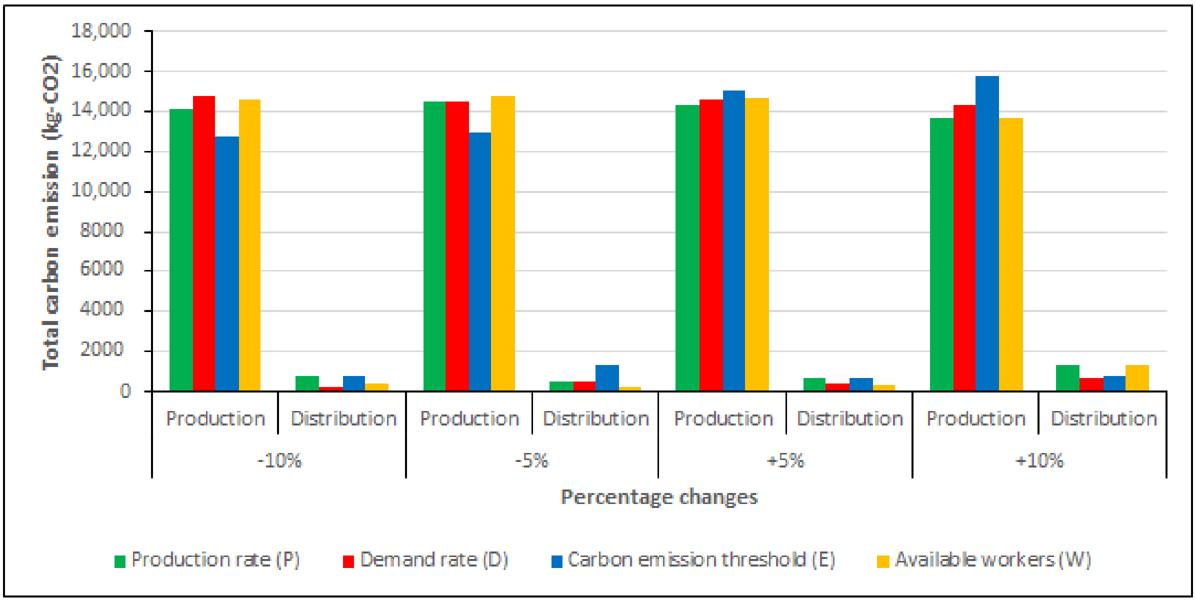

Figure 7. The effect of production, demand, carbon emission threshold value, and available workers on total carbon emission (kg-CO_2).

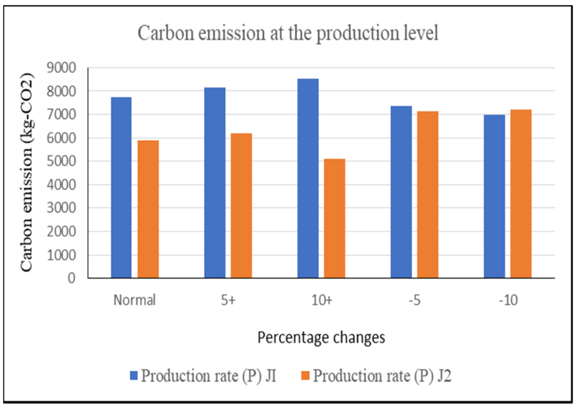

Figure 8. Total carbon emissions at the production level.

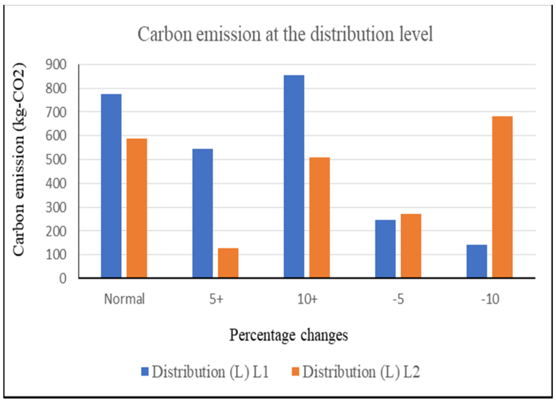

Figure 9. Total carbon emissions at the distribution center.

The sensitivity analysis results of carbon emission limits show a parameter that is sensitive to the total cost. Moon et al. [24] concluded that the amount of carbon offsets is cost-sensitive. In addition, Sarkar et al. [18] show that the carbon emission parameter affects the total cost, so that based on the sensitivity results, this parameter is in an equilibrium position. Another parameter in the study of Sarkar et al. [18] and Masudin et al. [74], namely the production level, shows that the production level parameter's sensitivity increases gradually with the total cost. Saga et al. (2019) found a sensitivity test on energy loss related to carbon emissions released to increase the total cost. Moreover, Sarkar et al. [72] analyzed the sensitivity to determine changes in the total cost of the supplier's carbon emission cost parameters and factory carbon emission costs. His research results show that the total cost increases if the supplier's carbon emission cost parameters and factory carbon emission costs increase. Mishra et al. [52] stated that the higher the level of social costs of carbon dioxide emissions, the lower the carbon dioxide emissions. Reducing the number of carbon emissions in production-distribution levels can be done by choosing trucks or transporters with lower carbon emissions [71]. Another way to reduce carbon emissions is applying green technology [52] and blockchain technology [22,75]. In contrast to Tseng and Hung [76], the government has to impose rules for companies to pay for carbon emission social costs in reducing carbon emissions.

5.2. Managerial Implications and Limitations

For the managerial implications from the results of this study, developing a production-distribution problem by integrating traceability and carbon emissions is providing policy recommendations to stakeholders involved in multi-echelon supply chains. From the government's perspective, the regulation of carbon emission has impacted significantly on the trading market. It is known that the government's carbon emission regulated by the government plays a significant role in the cost of the supply chain. Therefore, the local government should apply a wise carbon emission tax for industry sectors. Otherwise, it would affect the cost of production and distribution that would affect the country's economic performance [77]. A different tax of carbon emission for food and basic needs should be applied lower than commercial products as it would significantly impact the price of the products [78].

From the perspective of the industrial sectors, the results of this study indicate that the largest carbon emissions are generated from the production processes. Thus, top management of the production sectors should consider applying sustainable, lean, and green production approaches. Several approaches that can be used are green and lean manufacturing principles that can reduce carbon emissions significantly [79,80]. In addition, the recycling policy in the remanufacturing processes will greatly reduce carbon emissions [81].

This paper discussed the integration of production and distribution by considering traceability and carbon emissions to find the minimum total cost. However, some limitations should be addressed further. First, this study examines the supply chain system of manufacturers and distributors, not involving suppliers in the supply chain network. So that carbon emissions from suppliers have not been considered. Likewise, the total costs generated only involve manufacturers and distributors. In a previous study by Sarkar et al. [72], it was shown that the longer the supply chain network involved in the development of the model was, the more comprehensive were the results. The second limitation of this research is that it did not integrate the sustainability aspect into the design of the supply chain network. Previous research by Manuputi et al. [23] showed that the sustainability aspect is an important point to be involved in designing the supply chain network.

6. Conclusions

The integrated production-distribution model of canned fish products that considered emissions and traceability was successfully modeled from the research results. From this model, the minimum total cost was obtained. From the sensitivity analysis results, it was also found that the parameters of carbon emission limits and production levels are very sensitive with regard to the total costs. In contrast, the parameters of labor availability and the demand level changed but were not very sensitive with regard to total costs. In addition, the parameters of the production level, the level of demand, and the threshold value of carbon emissions can have a significant effect on producing total carbon emissions. Suggestions for further research are the development of a model by considering the central distributor's service level in meeting customer demands and considering multi-mode transportation.

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