Received 8 October 2022
Revised 7 December 2022
3 February 2023
Accepted 7 February 2023

# Model of multiperiod production-distribution for closed-loop supply chain considering carbon emission and traceability for agri-food products

Rahmi Yuniarti
*Department of Industrial Engineering, Universitas Brawijaya, Malang, Indonesia*
Ilyas Masudin
*Department of Industrial Engineering, Universitas Muhammadiyah Malang, Malang, Indonesia*
Ahmad Rusdiansyah
*Department of Industrial and Systems Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia, and*
Dwi Iryaning Handayani
*Department of Industrial Engineering, Universitas Panca Marga Probolinggo, Probolinggo, Indonesia*

## Abstract

**Purpose** – This study aimed to develop the integration of the multiperiod production-distribution model in a closed-loop supply chain involving carbon emission and traceability. The developed model was for agricultural food (agri-food) products, considering the reverse flow of food waste from the disposal center (composting center) to producers.

**Findings** – The results indicate that integrating the production and distribution model considering food waste recycling provides low carbon emissions in lower total costs. The sensitivity analysis also found that there are trade-offs between production and distribution rate and food waste levels on carbon emission and traceability.

**Research limitations/implications** – This study focuses on the mathematical modeling of a multiperiod production-distribution formulation for a closed-loop supply chain.



*Funding*: No funding was received to assist with the preparation of this manuscript.

*Author contributions*: Rahmi Yuniarti (RY) and Ilyas Masudin (IM) prepared the manuscript. RY and Dwi Iryaning Handayani (DH) modeled the formulations and interpreted the data. RY and Ahmad Rusdiansyah (AR) perform data collection, simulation and supervision. RY and IM were the major contributors to writing the manuscript. All authors read and approved the final manuscript.

*Statement of informed consent*: There are no human subjects in this article, and informed consent is not applicable.

*Data availability*: The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

*Code availability*: Not applicable.

*Conflict of interest*: The authors hereby declare that there are no potential conflicts of interest in terms of authorship, research and/or publication of this article.

International Journal of Industrial Engineering and Operations Management
Vol. 5 No. 3, 2023
pp. 240-263
Emerald Publishing Limited
e-ISSN: 2690-6104
p-ISSN: 2690-6090
DOI 10.1108/IJIEOM-10-2022-0045

**Originality/value** – The model of the agri-food closed-loop supply chain in this study that considers food recycling and carbon emissions would help stakeholders involved in the agri-food supply chain to reduce food waste and carbon emissions.

**Keywords** Production-distribution, Integration, Closed-loop supply chain, Food waste, Carbon emission, Traceability

**Paper type** Research paper



## 1. Introduction

As the human population increases, it has affected the availability of food supplies for consumption. The scarcity of food from agricultural sources that are increasingly limited has resulted in increasingly severe threats to humankind. Agricultural food (agri-food) products are one of the commodities that need more attention. This is because agri-food products have product characteristics prone to damage and quick decline in quality. With a short product life, the production and distribution process along the supply chain flow of agri-food products has the risk of damage that cannot be produced or repaired, which will become food waste. The largest source of agricultural product food waste along the supply chain network is in the production and distribution process (Göbel *et al.*, 2015; Scherhaufer *et al.*, 2018). A study by Annosi *et al.* (2021) indicates that 30% of the food waste is along with the production and distribution processes of the agri-food supply chain networks.

Research related to reducing food waste in perishable food products by paying attention to the integration of production and distribution has been widely discussed. For example, Amorim *et al.* (2013) stated that the discussion of the integration of production and distribution in the supply chain network is growing in importance in the area of perishable products. Moreover, the linking of manufacturing and distribution processes has been examined by Nair (2005) in the supply chain context who found that manufacturing and distribution strategies significantly impact performance measures. Solina and Mirabelli (2021) also developed integrative production and distribution models to reduce food waste in the supply chain environment. Every actor in the production-distribution chain must assure food safety and quality through the handling, manufacturing, packaging and transportation of products, making the traceability system essential (Kresna *et al.*, 2017). Yeh *et al.* (2019) employed a traceability system to maintain the safety and freshness of fish products throughout the production-distribution process. Similarly, Mawengkang and Mathelinea (2018) who developed a production-integration model in the marine product processing industry by taking the traceability system into account, are the only study that has looked into this. Companies must combine production-distribution while taking traceability into account to be profitable, yet carbon emissions must be controlled. To be profitable, businesses must combine production and distribution while taking traceability into account, yet it is crucial to limit carbon emissions (Yadav *et al.*, 2021). This is because some of the process' overall carbon emissions will be expensive. Carbon emissions are becoming more critical in this aspect, and businesses need to take note (Manupati *et al.*, 2019).

In terms of the variables considered in the integrative production-distribution models, some studies include different variables in the models. For example, Handayani *et al.* (2021) developed a mathematical model for producing and distributing perishable products considering carbon emission and traceability to minimize total costs. Moreover, Farahani *et al.* (2012) investigated the effect of food quality on production and distribution planning integration by shortening the time travel between production and distribution. Various studies have been conducted in the field of perishable foods such as fruits and vegetables (Ahumada and Villalobos, 2009; Osvald and Stirn, 2008; Shukla and Jharkharia, 2013). One of the earliest studies conducted by Ahumada and Villalobos (2009) focused on a simulation model in Agrifood Supply Chain (ASC) of various perishable and nonperishable agri-foods and vegetables. Furthermore, Verdouw *et al.* (2010) developed a basic model for designing fresh and processed fruit supply chain (SC). Zhang and Wilhelm (2011) presented a mathematical model for the crop industry, including vegetables, fruits, ornamental plants, tree nuts, berries and dried fruits. Shukla and Jharkharia (2013) published a literature review from 1991 to 2011 on the production of fresh produce such as fruits, flowers and vegetables. In addition, several studies have been conducted on mathematical models in the field of ASC and food supply chain (FSC). A transport planning model for FSC, in which several storage centers provide fruit logistics centers on demand during low seasons, was developed by Nadal-Roig and Plà-Aragonés (2015). Although there has been much discussion regarding the integration of production and distribution in supply chains and the variables involved in the model, few researchers have paid much attention to recycling spoiled food products for processing into fertilizers. The integration of production and distribution of perishable food products in a closed-loop supply chain environment by considering carbon emissions and recycling use from disposal centers has never been carried out. Literature studies carried out in the context of this research have supported the mathematical modeling of agricultural supply design optimization. This paper proposes a multiperiod model, a multilevel network closed-loop supply chain (CLSC) that includes farmers as producers, distribution centers, customer locations and composting centers. In this study, the vermicompost facility is one method of recycling organic waste (vegetables), which is considered reverse flow. This process results in a significant amount of organic fertilizer, which can maintain human health and the environment. Thus, this study aims to develop a production and distribution integration model by considering traceability and carbon emissions for total costs in a closed supply chain. Total costs include production, processing and packaging, transportation, inventory, finished product inventory, production carbon emissions, shipping carbon emissions and traceability costs. The model of the integrative production and distribution model considering carbon emission and traceability in this study could provide the decision-makers to configure a sustainable agri-food closed-loop supply chain.

This article has a five-section structure. The first part (introduction) explains the background knowledge and findings between the previous research and the research statement. The second section discusses studies that are relevant to the production-distribution optimization model approach. The following is the proposed approach (third section), which describes the methods, and the fourth section discusses the results and discussion. In this section, a discussion of the results and sensitivity analysis were done by developing a recommendation to stakeholders. Finally, section five is the conclusions and further potential research.

## 2. Literature review

This study uses a literature review to identify optimization approaches that researchers and practitioners widely use to solve, which researchers in modeling production-distribution integration problems have widely used. In addition, it also reviews the production-distribution integration model in the closed-loop supply chain for perishable products. Finally, at the end of the literature review, we discuss the previous literature related to the variables involved in the integrated production-distribution model in the closed-loop supply chain for agri-food products.

### *2.1 Mixed integer programming and optimization*

Mixed-integer programming is one of the most commonly used linear model developments in solving production and distribution optimization problems. The advantage of this mixed integer linear programming (MILP) compared to linear programming (LP) is that MILP can accommodate integer variables in the decision variables and constraints of the developed model (Moretti *et al.*, 2021). In terms of the production-distribution model in agri-food products, the MILP approach is widely applied. de Keizer *et al.* (2015) Modeled the production-distribution problem into MILP models for food products. For example, the production and distribution integration model used MILP to determine detailed product quality service levels. Other studies by Liu and Papageorgiou (2013) that developed an integrative production-distribution model for perishable food products showed that MILPeffectively solved multiobjective problems. Moreover, Meisel *et al.* (2013) provided a production and inter-modal transportation planning model and found a 6% saving in the integrated models. Regarding the complexity of problem-solving, some studies show that MILP is superior in solving the complex model of binary variables of the production-distribution problem. For example, Safaei *et al.* (2010) developed a multisite production-distribution model to decrease the costs of set up, production, inventory, distribution and transportation. Moreover, Thanh *et al.* (2008) and Masudin (2015) show the effectiveness of the MILP approach in solving location problems in the design of complex supply chains.

Goal programming, mixed-integer linear and non-LP models, and the traceability case optimization approach are employed. The most frequently used model in the literature is called MILP. Rong and Grunow are two researchers who have employed an optimization strategy to address traceability issues (Rong and Grunow, 2010). Utilizing the MILP technique, they created production and distribution planning to manage food safety risks in food supply chains based on traceability. The MILP concept was also put up by Moniz *et al.* (2013) to schedule production while taking traceability into account. Gautam *et al.* (2017) used a multiobjective integer non-LP (MOINLP) method, taking into account two objective functions to reduce the cost of logistics overall, the cost of adopting radio frequency identification (RFID) for traceability and the cost of contamination in the kiwifruit supply chain. Mawengkang and Mathelinea (2018) carried out the same study. Utilizing the MILP technique, their study takes traceability into account when production and distribution are planned to satisfy consumer demand for high-quality products.

### *2.2 Production-distribution optimization in closed-loop supply chain*

The integration of production and distribution in the traditional conventional supply chain management network is widely discussed. However, reverse logistics processes such as recycling, remanufacturing and redistribution for closed-loop supply chain systems should be further considered in an integrated production and distribution model. Afra and Behnamian (2021) developed a multiproduct production and routing problem considering remanufacturing process in the model. Their model includes product return for remanufacturing and restoration for redistribution with startup costs and environmental considerations. Moreover, Jing and Li (2018) modeled the integration of production and distribution in a closed-loop supply chain network. They consider remanufacturing and recycling processes in a decentralized closed-loop supply chain system. Other studies developed an integrative production and distribution in closed-loop supply chain networks considering reverse logistics such as reuse (Ech-Charrat *et al.*, 2017), redistribution (Zahedi *et al.*, 2021) and recycling (Masudin *et al.*, 2019).

One of the environmental problems in SC is the amount of waste produced which is responded to by the recycling process, attracting the attention of experts and researchers (Piyathanavong *et al.*, 2019). Restoring the value of a product involves reverse logistics activities such as recycling, product improvement and waste management (Domínguez-Caamaño *et al.*, 2017). Therefore, reverse logistics includes activities that start with used products until they can be reused in the market (Fleischmann *et al.*, 1997). The importance of reverse logistics produces economic benefits and has a positive social image for the company

(Kannan *et al.*, 2012). Therefore, better evaluation of product returns and effective back logistics can have an impact on competitive advantage. Several reverse logistics network design models have been developed as CLSC which is defined as a chain in which forward and reverse logistics are combined. In CLSC, material flow is circular, and manufactured products are not disposed of after use, but rather disassembled, reused, recovered, or recycled as raw materials and remarketed to consumers (Mangla *et al.*, 2018). Pishvaee and Torabi (2010) presented a mixed integer LP model to minimize investment costs and transportation costs in a reverse logistics network using a multiechelon annealing simulation algorithm.

*2.3 Production-distribution optimization, carbon emission and traceability*

Several researchers have optimized the production-distribution integration model by considering environmental variables. The environmental variables included in the model, such as carbon emission, energy reduction and traceability, have been studied by several researchers. Manupati *et al.* (2019) included carbon emission in the production-distribution model for a sustainable supply chain system. Their integrated production and distribution model was developed for a multiechelon supply chain network considering three policies of carbon emission: carbon tax, strict carbon capping and carbon cap-and-trade. Other studies by Moon *et al.* (2016) proposed bi-objective optimization problems of production and distribution integration. They developed four stages production-distribution system under carbon emission constraints using mixed-integer programming. Moreover, Wang *et al.* (2021b) integrated production and transportation problems for the e-commerce supply chain by involving carbon emissions in the model. Their integration model focused on analyzing the transportation scheduling model to optimize carbon emissions and costs.

The traceability system in the supply chain network has been paid more attention. Some studies attempted to elaborate on the impacts of the traceability system on the performance of the supply chain. For example, in the context of traceability, some studies have discussed the integration of production and distribution models. Masudin *et al.* (2021) and Yüksel (2022) investigated the relationship between traceability and supply chain performance. They found that the traceability system impacts significantly on supply chain performance. Other studies by Costa *et al.* (2013) included traceability in their production-distribution model. They constructed reference processes of agri-food tracking for the foundation of food safety. Moreover, Handayani *et al.* (2021) developed a production and distribution integration model with the constraint of traceability to minimize total costs. The study indicated that the proposed production and distribution model integration could produce the minimum total production and distribution cost with high traceability and low carbon emissions.

Several previous studies researched the integration of production and distribution in supply chain networks that took into account the presence of carbon emissions as shown in Table 1. Gautam *et al.* (2017) took a case study of the kiwifruit supply chain and analyzed the impact of traceability using RFID tags. Using a (MOINLP) model is formulated by considering two objective functions which include (1) minimizing the total cost of combining logistics costs and the cost of implementing RFID tags and (2) the cost of liability for contamination. Meanwhile, Manupati *et al.* (2019) differs from production-distribution and inventory problems in a multiechelon supply chain with three carbon policies, strict carbon and cover, and carbon trading and time considerations by developing a nonlinear mixed integer programming model. In another study, Usman *et al.* (2018), developed a reliable initial model of an integrated traceability system for the halal food supply chain. The method is based on a unified modeling language (UML) such as use cases, sequences, and business process diagrams. The objective model is formulated by considering two objective functions which include (1) the risk of failure that may occur during outbound logistics activities and (2) maximizing the quality of information on halal products. Furthermore, Jabarzadeh *et al.* (2020) used a multiobjective mixed-integer LP method to solve the optimization model for perishable

| Authors | Network supply chain | Concern | | Approach |
|---|---|---|---|---|
| | | Carbon emission | Traceability | |
| Rong and Grunow (2010) | Forward | – | √ | Mixed-integer linear programming |
| Kallel and Benaissa (2011) | Forward | – | √ | Mixed-integer linear programming |
| Gautam *et al.* (2017) | Forward | – | √ | Multi-objective integer nonlinear programming |
| Moon *et al.* (2016) | Forward | √ | – | Mixed-integer linear programming |
| Mawengkang and Mathelinea (2018) | Forward | – | √ | Mixed-integer linear programming |
| Manupati *et al.* (2019) | Forward | √ | – | Mixed-integer programming |
| Zhang *et al.* (2017) | Forward | √ | – | Mixed-integer linear programming |
| Usman *et al.* (2018) | Forward | – | √ | Goal Programming |
| Jabarzadeh *et al.* (2020) | Closed Loop SC | – | √ | Mixed-integer linear programming |
| Proposed Model | Closed Loop SC | √ | √ | Mixed-integer linear programming |

**Source(s):** Authors work

**Table 1.** Comparison of models related to the proposed research topic

products in terms of total network costs and carbon emissions and maximize responsiveness to demand. Meanwhile, Zhang *et al.* (2017) proposed the MILP model for multiitem production scheduling by considering carbon emissions in production. The MILP method was also chosen by Moon *et al.* (2016) in formulating the trade-off problem between optimal advantages and disadvantages in production-distribution planning with carbon emission limits and inaccurate information about raw material resources. On the other hand, our literature review shows that MILP has been widely proposed for production-distribution problems related to traceability and carbon emissions. However, the MILP method for combining traceability and carbon emissions in production distribution issues is still limited. Therefore, this study proposes the MILP method by considering traceability and carbon emissions simultaneously.

## 3. Research methodology

The initial stage in this research is determining the supply chain actors involved in the model to be developed. The supply chain actors in this model are farmers as producers, distribution centers, customers and composting centers whose function is to recycle organic vegetables from distribution centers and customers. The next stage is to develop a mathematical model formulated using the MILP approach. The goal of this study is to create a mathematical model utilizing the MILP method. When it comes to identifying actual issues, such as food waste, carbon emissions and traceability cost, MILP is thought to be helpful. In order to evaluate and test the proposed model's accomplishment, a numerical analysis based on actual examples was conducted. The sensitivity analysis, meantime, looks at the effects of changes on the performance output. MILP is considered effective in capturing real problems, such as food waste, carbon emissions, long-distance shipping and traceability. This mathematical model is designed for a multiperiod and multiproduct in closed loop vegetable supply chain. The next stage is to determine the parameters and decision variables needed in the model. The decision variables determined are the location of the farmer and the number of vegetables that must be produced, the number of vegetables that must be sent to the distribution center, the level of inventory at the distribution center and distribution center, the level of carbon emissions resulting from processing vegetables at the distribution center, and the level of carbon emissions produced from the distribution center. The following decision variables are the number of vegetables sent from the farmer distribution center, the amount of vegetable waste sent from the distribution center to the composting center, the amount of vegetable waste sent from customers to the composting center and the amount of compost sent to the composting center.

The mathematical model developed aims to minimize costs, including production costs at producers and distribution centers, transportation costs, storage costs, carbon emission costs, traceability costs and the composting process.

Furthermore, numerical analysis was conducted to test and assess the proposed model. Meanwhile, sensitivity analysis was conducted to determine the impact of changes on output performance. The parameters in the sensitivity test were.

(1) The level of production from farmers,

(2) The level of consumer demand,

(3) The cost of producing agri-food products for farmers, and

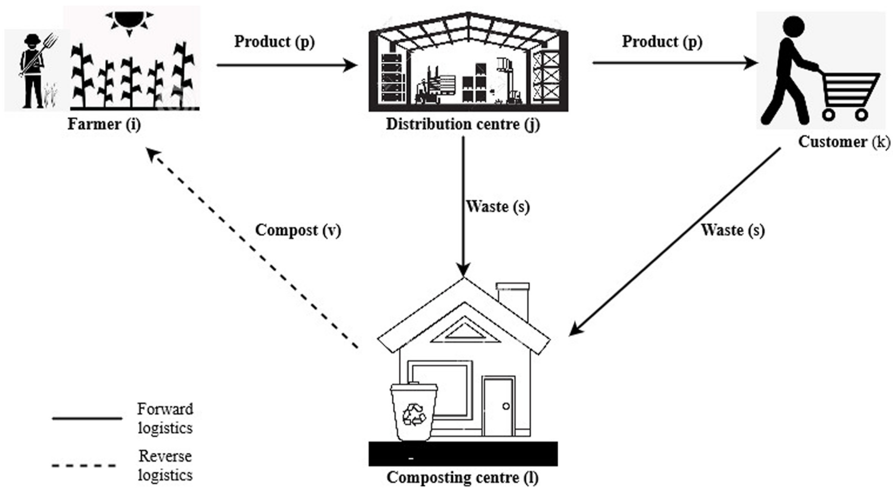
(4) The percentage of food waste produced by consumers of agri-food products.

Based on the developed model and the sensitivity test results are then analyzed. The results of this study would be discussed from different perspectives and the recommendations for involved stakeholders are proposed at the end of the discussion section.

## 4. Model development

### *4.1 Integration of production-distribution models in the agricultural food closed-loop supply chain*

In this study, a production and distribution integration model was developed to optimize the CLSC performance of organic agri-food products from the economical aspect by considering carbon emissions, product traceability and food waste processing of organic agri-food products. The logistics network is a multiperiod for multiproducts consisting of four echelon types, including producers (farmers), distribution centers, markets and composting centers, as shown in Figure 1. Mathematical model of integration of production-distribution network formulated




**Source(s):** Authors work

**Figure 1.** Production-distribution network on closed-loop supply chain

into a mathematical model using a mixed-integer programming approach. This model allows decision-makers to optimize inventory levels and distribution on the CLSC concept of organic agri-food products. At the model testing stage, numerical analysis is based on real case examples in the agri-food supply chain industry. At the model testing stage, numerical analysis is done based on real case examples in the agri-food supply chain industry. This analysis was carried out to give a general picture of the effectiveness and evaluation of the suggested model. In this model, there are three product forms, including organic vegetables, food waste and compost, where the details of the movement of the three products are as follows:

(1) Fresh and agri-food products are sent to producers (farmer) distribution centers. The observed period is two periods.

(2) The agri-food waste products from the distribution center and consumers are sent to the compost processing center.

(3) Compost products from organic agri-food waste processing are obtained from the amount of waste product conversion at the composting center, and then delivered to agri-food producers (farmers).

Figure 1 shows the organic agri-food production system with $p = 1, 2, \ldots P$ produced by the farmer as much as $i = 1, 2, \ldots I$. After harvesting, the organic agri-food is sent to the distribution center as much as $j = 1, 2, \ldots J$ for packaging. This packaging process produces carbon emissions with a threshold that has been set according to government regulations. In addition, during the distribution process, carbon emissions can also arise. Agri-food can then be sold to the market (customer) with a demand pattern from the end customer. The rotten organic agri-food cannot be consumed, so it is sent to the composting center as much as $l = 1, 2, \ldots L$ for processing organic agri-food waste into compost. The finished compost is sent back to the producers (farmers) to be used as organic fertilizer.

The development of the production-distribution integration model in a closed-loop supply chain for organic agri-food products depicted in Figure 1 considers several assumptions, including (1) the farmer's location, distribution center, customer and composting center has been determined previously, (2) the quality of the agri-food industry. For example, food products that decreased at the distribution center and the customer could not be used anymore were transferred to the composting center and (3) the initial inventory at the farmer's location, the distribution center was zero.

*4.1.1 Index.* The index used in the developed model is as follows:

Time period with index t, $t = 1, 2, \ldots T$

Agri-food organic products with index p, $p = 1, 2, \ldots P$

Farmer with index i, $i = 1, 2, \ldots I$

Distribution center with index j, $j = 1, 2, \ldots J$

Customer with index k, $k = 1, 2, \ldots K$

Organic food waste with index s, $s = 1, 2, \ldots S$

Composting center with index l, $l = 1, 2, \ldots L$

Compost with index v, $v = 1, 2, \ldots V$

*4.1.2 Parameter.* The parameters used in the developed model are as follows:

$D_{pjt}$: agri-food product demand (p) at distribution center (j) in period t (tons)

$CP_{pit}$: cost of producing agri-food product (p) to farmer (i) in period t ($/ton)

$CG_{pjt}$: cost of processing and packing agri-food product (p) at distribution center (j) (\$/ton)

$Cs_{pit}$: storage cost (p) to farmer (i) in period t (\$/ton)

$Ch_{pjt}$: storage cost (p) at distribution center (j) in period t (\$/ton)

$Ce_{pjt}$: carbon emission cost for processing and packing product (p) at distribution center (j) in period t (\$/kg-$CO_2$/ton)

$Ct_{ijt}$: carbon emission cost for delivery from farmer (i) to distribution center (j) in period t (\$/kg-$CO_2$/ton)

$Ec_{pjt}$: carbon emission level for processing and packaging food products (p) at

distribution center (j) in period t (kg-$CO_2$/ton)

$Et_{pjt}$: level of carbon emission produced in the process of shipping food product (p) in period t (kg-$CO_2$/ton)

$alpha_t$: percentage of food waste (s) wasted in distribution center (j) in period (t) (%)

$beta_t$: percentage of food waste (s) wasted on customers (k) in period (t) (%)

w: conversion rate of fruit into composting center

$Ck_{slt}$: the cost of making compost from food waste (s) in composting center (l) in period t (\$/ton)

$VC_p$: variable cost for delivery of food product (p) or waste (w) (\$)

$d_{ij}$: distance from farmer (i) to distribution center j (km)

$d_{jk}$: distance from distribution center (j) to customer (k) (km)

$d_{jl}$: distance from distribution center (j) to composting center (l) (km)

$d_{kl}$: distance from customer (k) to composting center (l) (km)

$d_{li}$: distance from composting center (l) to farmer (i) (km)

$Cc_{pj}$: food product traceability cost (p) at distribution center (j) in period t (\$/ton)

*4.1.3 Decision variables.* The decision variables used in the developed model are as follows:

$Y_{pj}$: binary variable, value 1 if agri-food production (p) is done and value 0 otherwise

$P_{pit}$: number of agri-food (p) produced by farmer (i) in period t (tons)

$X_{pijt}$: number of agri-food (p) sent from farmer (i) to distribution center (j) in period t (tons)

$Is_{pit}$: agri-food inventory level (p) on farmer (i) in period t (tons)

$Ih_{pjt}$: agri-food inventory level (p) at the distribution center (j) in period t (tons)

$ECP_{pjt}$: agri-food processing carbon emission level (p) at distribution center (j) in period t (kg-$CO_2$/ton)

$ECT_{ijt}$: carbon emission level from agri-food delivery process (p) from a farmer (i) to distribution center (j) in period t (kg-$CO_2$/ton)

$Ws_{jlt}$: the amount of agri-food waste (s) sent from distribution center (j) to composting center (l) in period t (tons)

$Ww_{klt}$: the amount of agri-food waste (s) sent from the customer (k) to composting center (l) in period t (tons)

$Wc_{lit}$: the amount of compost (v) that can be sent from composting center (l) to farmer (i) in period t (tons)

### 4.2 Mathematical model

The framework shown in Figure 1 can be formulated mathematically to minimize the total cost. The costs formulated are costs for production costs at producers and distribution centers, transportation costs, storage costs, carbon emission costs, traceability costs and the cost of the composting process. Therefore, the objective function equation to minimize total cost can be formulated as follows:

$$
\begin{aligned}
Minimize\ TC = & \left(\sum_{p\in P}\sum_{i\in I}\sum_{t\in T} CP_{pit}P_{pit} + \sum_{p\in P}\sum_{j\in J}\sum_{t\in T} CG_{pjt}X_{pijt}\right) \\
& + \left(\sum_{p\in P}\sum_{i\in I}\sum_{j\in J}\sum_{t\in T} X_{pjt}d_{ij}VC_p + \sum_{p\in P}\sum_{j\in J}\sum_{k\in K}\sum_{t\in T} D_{pjt}d_{jk}VC_p\right. \\
& + \sum_{s\in S}\sum_{j\in J}\sum_{l\in L}\sum_{t\in T} Ws_{jlt}d_{jl}VC_p + \sum_{s\in S}\sum_{k\in K}\sum_{l\in L}\sum_{t\in T} Ww_{klt}d_{kl}VC_p \\
& \left. + \sum_{v\in V}\sum_{l\in L}\sum_{i\in I}\sum_{t\in T} Wc_{lit}d_{li}VC_p\right) + \left(\sum_{p\in P}\sum_{i\in I}\sum_{t\in T} Cs_{pit}Is_{pit}\right. \\
& \left. + \sum_{p\in P}\sum_{j\in J}\sum_{t\in T} Ch_{pjt}Ih_{pjt}\right) + \left(\sum_{p\in P}\sum_{j\in J}\sum_{t\in T} Ce_{pjt}ECP_{pjt}\right. \\
& \left. + \sum_{i\in I}\sum_{j\in J}\sum_{t\in T} Ct_{ijt}ECT_{ijt}\right) + \left(\sum_{p\in P}\sum_{i\in I}\sum_{t\in T} Cc_{pj}P_{pit}\right) \\
& + \left(\sum_{j\in J}\sum_{l\in L}\sum_{t\in T} Ws_{jlt}Ck_{plt} + \sum_{k\in K}\sum_{l\in L}\sum_{t\in T} Ww_{klt}Ck_{plt}\right)
\end{aligned} \tag{1}
$$

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

$$\sum_{i\in I} P_{pit} \le \sum_{i\in I} X_{pijt} \tag{2}$$

$$P_{pit} \le Y_{pj}CP_{pit} \tag{3}$$

$$\sum_{j\in J} X_{pijt} \le P_{pit} \tag{4}$$

$$Is_{pit} = Is_{pi(t-1)} + P_{pit} - \sum_{j\in J} X_{pijt} \tag{5}$$

$$Ih_{pjt} = Ih_{pj(t-1)} + \sum_{i\in I} X_{pijt} - D_{pjt} \tag{6}$$

$$Is_{pit} + P_{pit} \geq \sum_{j \in J} X_{pijt} \quad (7)$$

$$Ih_{pjt} + \sum_{i \in I} X_{pijt} \geq D_{pjt} \quad (8)$$

$$Ws_{jlt} = \alpha_t Ih_{pjt} \quad (9)$$

$$Ww_{klt} = \beta_t D_{pjt} \quad (10)$$

$$Wc_{lit} = \left( \sum_{j \in J} \sum_{l \in L} \sum_{k \in K} \sum_{t \in T} Ws_{jlt} + Ww_{klt} \right) w \quad (11)$$

$$ECP_{pjt} = X_{pijt} Ec_{pjt} \quad (12)$$

$$ECT_{ijt} = X_{pijt} Et_{pjt} \quad (13)$$

$$Y_{pj}, \in \{0,1\} \, \forall l \in L \quad (14)$$

$$P_{pit}, X_{pijt}, Is_{pit}, Ih_{pjt}, ECP_{pjt}, ECT_{ijt}, Ws_{jlt}, Ww_{klt}, Wc_{lit} \geq 0 \, \forall i \in I, j \in J, k \in K, l \in L, t \in T \quad (15)$$

Constraint (2) ensures that the amount of agri-food product (p) produced by the farmer (i) does not exceed the farmer's capacity (i), while constraint (3) ensures that the amount of agri-food product (p) can be produced if the farmer (i) opened. Furthermore, constraint (4) ensures that the amount of agri-food product (p) delivered to distribution (j) does not exceed the amount of production at the farmer (i). Constraint (5) indicates the level of agri-food product inventory (p) at farmer (i) in period t (tons). Constraint (6) shows the level of agri-food product inventory (p) at the distribution center (j) in period t (tons), and constraint (7) ensures that the amount of agri-food product (p) in the farmer exceeds the number of products delivered to the farmer and distribution center (j). Moreover, constraint (8) ensures that the number of agri-food products (p) in the distribution center (j) exceeds the number of customer demands (k). Constraint (9) indicates the amount of agri-food product (s) wasted from the distribution center (j) by the percentage of agri-food products that become food waste. Constraint (10) shows the amount of agri-food product (s) wasted by customers (k) equal to the percentage of agri-food product that becomes waste from demand (k). Furthermore, constraint (11) indicates the amount of compost (v) that can be delivered from the composting center (l) to the farmer (i) in period t (tons). Constraint (12) indicates the level of carbon emissions from processing agri-food products at the distribution center (j), and constraint (13) indicates the level of carbon emission in the process of sending agri-food products from the farmer (i) to the distribution center (j). Finally, constraint (14) shows the binary number on the farmer (i), and constraint (15) shows the non-negativity value limit on the determined decision variable.

### *4.3 Data on agri-food product supply chain*

This study was conducted on Indonesia's supply chain network of organic agricultural products. The data used is historical data on customer requests to the distribution center. In this case study, two farmers, I1 and I2, produce two product types (P1 and P2) in two periods (t1 and t2). The production capacity produced by farmer 1 (I1) is 156 and 100 tons for products 1 and 2, respectively. Meanwhile, the production capacity produced by farmer 2 (I2) for products 1 and 2 is 120 and 166 tons, respectively. Moreover, there are two distribution centers (J1 and J2) that have different demands of product types (P1 and P2) in two periods (t1 and t2). For example, the demand at the distribution center is 223 and 244 tons for products 1 and 2, respectively. Farmers' production costs in producing each product are shown in Table 2. In the meantime, Table 3 displays the storage expenses for each product at the distribution facility.

This study considers the existence of carbon emissions generated in the distribution centers for the processing, packaging and delivery of agri-food. In the case study, the two operating distribution centers are J1 and J2, which distribute two types of agri-food products, namely P1 and P2. The carbon emission level for processing and packaging in the distribution center is 0.02 kg-$CO_2$/tons. The costs of carbon emissions for the processing, packaging and shipping processes of products are shown in Tables 4 and 5.

Based on the framework, the production and distribution network model require distance data between facilities. For example, the distance from farmers (I1 and I2) to distribution

| Farmer (I) | Product (P) | Period (t) 1 | 2 | Total |
|---|---|---|---|---|
| I1 | P1 | 65 | 65 | 130 |
| | P2 | 60 | 60 | 120 |
| I2 | P1 | 65 | 65 | 130 |
| | P2 | 60 | 60 | 120 |
| Total | | 250 | 250 | 500 |

**Source(s):** Authors work

**Table 2.** Cost of producing food product (p) on the farmer (i) in period t ($/ton)

| Distribution center (J) | Product (P) | |
|---|---|---|
| J1 | P1 | 40 |
| | P2 | 38 |
| J2 | P1 | 40 |
| | P2 | 38 |

**Source(s):** Authors work

**Table 3.** Cost of product storage (p) at the distribution center (j) ($/ton)

| Distribution center (J) | Product (P) | Period (t) 1 | 2 | Total |
|---|---|---|---|---|
| J1 | P1 | 1.5 | 1.5 | 3 |
| | P2 | 1.4 | 1.4 | 2.8 |
| J2 | P1 | 1.4 | 1.4 | 2.8 |
| | P2 | 1.5 | 1.5 | 3 |
| Total | | 5.8 | 5.8 | 11.6 |

**Source(s):** Authors work

**Table 4.** Cost of carbon emissions for processing and packaging the product (p) at the distribution center (j) in period t ($/$CO_2$/ton)

| Distribution center (J) | Product (P) | Period (t) 1 | 2 | Total |
|---|---|---|---|---|
| J1 | P1 | 1.5 | 1.5 | 3 |
| | P2 | 1.4 | 1.4 | 2.8 |
| J2 | P1 | 1.4 | 1.4 | 2.8 |
| | P2 | 1.5 | 1.5 | 3 |
| Total | | 5.8 | 5.8 | 11.6 |

**Source(s):** Authors work

**Table 5.** Cost of carbon emissions for delivery from the farmer (i) to distribution center (j) in period t ($/$CO_2$/ton)

centers (J1 and J2) is 50 and 80 km, respectively. Moreover, the distance from distribution centers (J1 and J2) to customers (K1 and K2) is 20 and 50 km. Moreover, the distance between the distribution center (J1 and J2) to the composting center (L1 and L2) is 69 and 104 km. In addition, the distance from customers (K1 and K2) to composting centers (L1 and L2) is 10 km and 20 km respectively, while the distance from composting centers (L1 and L2) to farmers (I1 and I2) is 90 and 52 km, respectively.

In this case study, the storage cost of agri-food products to the farmer (i) is $5/ton. Meanwhile, the cost of processing and packaging agri-food products at the distribution center is $20/ton. The carbon emissions in shipping agri-food products are 0.05 (kg-$CO_2$/ton). The percentage of agri-food product waste at the distribution center at the time of observation was 13% and 12%, respectively. Furthermore, the percentage of agri-food product waste originating from customers during the observation period was 12% and 11%, respectively. The conversion rate of agri-food waste products into compost is 110%. The cost of composting from agri-food waste products is $7/ton. The variable cost for delivering agri-food products or waste is $0.073/ton. The cost of traceability of agri-food products at the distribution center is $25/ton.

### *4.4 Results*

Based on the solver calculations, the total cost incurred by the closed-loop supply chain network of organic agri-food is $55.205. Table 6 shows all the components that make up the total costs in the closed-loop supply chain network of organic agri-food products. The table shows that the highest cost composition is the cost of the organic product agri-food cultivation process, contributing 52.81% of the total cost. The delivery of food products from farmers to the distribution center is equal to the consumer demand, so there is no food waste in the distribution center for the two types of products. This results in no food waste distribution from the distribution center to the composting center, so the transportation cost from the distribution center to the composting center is $0. Additionally, this results in zero costs for the distribution center's inventory and for composting vegetable waste generated there.

| Cost component | Amount ($) | Percentage (%) |
|---|---|---|
| Cost of producing Agri-food at farmers | 29.155 | 52.8123 |
| Processing and packaging costs at the distribution center | 9.340 | 16.9188 |
| Transportation costs from Farmer to distribution center | 2.595 | 4.7023 |
| Transportation costs from distribution center to customer | 984.77 | 1.7838 |
| Transportation costs from the distribution center to composting center | 0.00 | 0.0000 |
| Transportation costs from the customer to the composting center | 59.59 | 0.1079 |
| Transportation costs from composting center to Farmer | 302.14 | 0.5473 |
| Farmer inventory costs | 310 | 0.5615 |
| Inventory costs at distribution center | 0.00 | 0.0000 |
| Cost of carbon emissions for packaging | 0.19 | 0.0003 |
| Cost of shipping process carbon emissions | 407 | 0.7373 |
| Cost of traceability product | 11675.00 | 21.1485 |
| Cost of composting food waste from distribution center to composting center the | 0.00 | 0.0000 |
| Cost of composting food waste from the customer to the composting center | 375.41 | 0.6800 |
| *Total cost* | *55.205* | *100* |

**Source(s):** Authors work

**Table 6.**
Cost calculation results

The optimal results from the calculation for the number of agri-food products produced and delivered by the farmer to the distribution center, the amount of waste sent from the customer to the composting center and the amount of compost sent from the composting center to the farmer can be seen in Tables 7–14.

Based on the results of data processing using the solver in the spreadsheet, the two farmers were open to meeting the demands of the agri-food product market. As a result, the number of agri-food products (p) produced can be seen in Figure 2, which shows that farmer 2 (i2) produces more products in both types of agri-food products because of the capacity of farmer 2 (i2) is greater than the capacity of farmer 1.

Table 11 shows that the total carbon emission level in the distributor packaging process is lower than the total carbon emission in the delivery process from farmers to distribution centers. This is because the packaging process carried out by distributors is simple, so carbon emissions from the process are low. In comparison, the delivery process uses gasoline-fueled vehicles, so the resulting carbon emissions are more significant than the packaging process.

| Farmer (I) | Product (P) | Period (T) 1 | 2 | Total |
|---|---|---|---|---|
| I1 | P1 | 1 | 1 | 4 |
| | P2 | 1 | 1 | 4 |
| I2 | P1 | 1 | 1 | 4 |
| | P2 | 1 | 1 | 4 |
| Total | | 4 | 4 | 8 |

**Source(s):** Authors work

**Table 7.** Binary variable agri-food product (p) produced by the farmer (i)

| Farmer (I) | Product (P) | Period (T) 1 | 2 | Total |
|---|---|---|---|---|
| I1 | P1 | 50 | 60 | 110 |
| | P2 | 50 | 50 | 100 |
| I2 | P1 | 57 | 60 | 117 |
| | P2 | 69 | 71 | 140 |
| Total | | 226 | 241 | 467 |

**Source(s):** Authors work

**Table 8.** Agri-food products (p) quantity produced by the farmer (i) in period t (tons)

| Farmer (I) | Distribution center (J) | Product (P) | Period (T) 1 | 2 | Total |
|---|---|---|---|---|---|
| I1 | J1 | P1 | 50 | 50 | 115 |
| | | P2 | 0 | 0 | 0 |
| | J2 | P1 | 0 | 0 | 5 |
| | | P2 | 50 | 50 | 100 |
| I2 | J1 | P1 | 0 | 0 | 0 |
| | | P2 | 60 | 58 | 118 |
| | J2 | P1 | 57 | 60 | 117 |
| | | P2 | 9 | 13 | 22 |
| | Total | | 226 | 241 | 467 |

**Source(s):** Authors work

**Table 9.** Agri-food products (p) quantity delivered from farmer (i) to distribution center (j) in period t (tons)

Figure 3 illustrates the level of carbon emissions from the processing of agri-food products at distribution centers which shows that the amount of carbon emissions released is influenced by the number of products processed and the level of carbon emissions in each process. The more products are processed at the distribution center, the more carbon emissions will increase.

The agri-food waste from the customer can be seen in Figure 4. The waste is sent to the composting center to be processed into compost and returned to the farmer to be used as fertilizer to plant agri-food products.

Based on Table 6, the results of the cost traceability calculation are 21.1485% of the total cost. Product traceability costs are affected by the amount of product processed and packaged. Traceability costs cover the movement of agro-food products through the production, packaging and distribution stages. In this case, traceability traces and detects

**Table 10.** Inventory level of agri-food product (p) at Farmer (i) in period t (tons)

| | | Period (T) | | |
|---|---|---|---|---|
| Farmer (I) | Product (P) | 1 | 2 | Total |
| I1 | P1 | 0 | 0 | 0 |
| | P2 | 0 | 0 | 0 |
| I2 | P1 | 0 | 0 | 0 |
| | P2 | 18 | 44 | 62 |
| Total | | 18 | 44 | 62 |

**Source(s):** Authors work

**Table 11.** The carbon emission level of processing agri-food products (p) at the distribution center (j) in period t (kg-$CO_2$/ton)

| | | Period (T) | | |
|---|---|---|---|---|
| Distribution center (J) | Product (P) | 1 | 2 | Total |
| J1 | P1 | 1.00 | 1.10 | 2.10 |
| | P2 | 1.20 | 1.16 | 2.36 |
| J2 | P1 | 1.14 | 1.30 | 2.44 |
| | P2 | 1.18 | 1.26 | 2.44 |
| Total | | 4.52 | 4.82 | 9.34 |

**Source(s):** Authors work

**Table 12.** Level of carbon emission in the process of delivering agri-food products (p) from farmer (i) to distribution center (j) in period t (kg-$CO_2$/ton)

| | | | Period (T) | | |
|---|---|---|---|---|---|
| Farmer (I) | Distribution center (J) | Product (P) | 1 | 2 | Total |
| I1 | J1 | P1 | 2.50 | 2.75 | 5.25 |
| | | P2 | 0 | 0 | 0 |
| | J2 | P1 | 0 | 0.25 | 0.25 |
| | | P2 | 2.50 | 2.50 | 5 |
| I2 | J1 | P1 | 0 | 0 | 0 |
| | | P2 | 3 | 2.90 | 5.90 |
| | J2 | P1 | 2.85 | 3 | 5.85 |
| | | P2 | 0.45 | 0.65 | 1.10 |
| | Total | | | | 23.35 |

**Source(s):** Authors work

agri-food products through (i) the stages of farmer production, the packaging process at the distribution center, (j) and the transportation process. With this traceability system, consumers can find out what, when, how and where products are processed, packaged and shipped.

### *4.5 Discussion*

Food-related items produce emissions during manufacture and delivery. Prashar (2020) and Saga *et al.* (2019) indicated that the increasing number of products manufactured and distributed along the supply chain would result in carbon emissions increasing. The findings of this study have shown that food manufacturing and distribution activities contribute to carbon emissions. It also shows that total carbon emissions in the production process are smaller than the total distribution of carbon emissions. For example, the total carbon emission generated in distribution activities is 23.35 kg-$CO_2$ (71%). Meanwhile, the total

**Table 13.** Amount of agri-food waste(s) sent from customer (k) to composting center (l) in period t (tons)

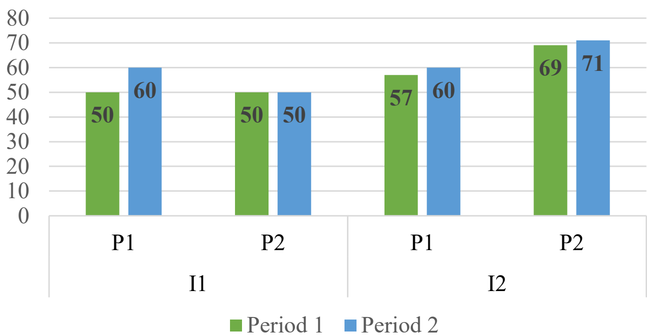
| Customer (K) | Composting center (L) | Product (P) | Period (T) 1 | 2 | Total |
|---|---|---|---|---|---|
| K1 | L1 | S1 | 6 | 6.05 | 12.05 |
| | | S2 | 7.20 | 6.38 | 13.58 |
| K2 | L2 | S1 | 6.84 | 7.15 | 13.99 |
| | | S2 | 7.08 | 6.93 | 14.01 |
| | Total | | 27 | 27 | 53.63 |

**Source(s):** Authors work

**Table 14.** The amount of compost (v) that can be sent from the composting center (l) to the farmer (i) in period t (tons)

| Composting center (L) | Farmer (I) | Product (P) | Period (T) 1 | 2 | Total |
|---|---|---|---|---|---|
| L1 | I1 | P1 | 6.60 | 6.66 | 13.26 |
| | | P2 | 7.92 | 7.02 | 14.94 |
| L2 | I2 | P1 | 7.52 | 7.87 | 15.39 |
| | | P2 | 7.79 | 7.62 | 15.41 |
| | Total | | 30 | 29 | 58.99 |

**Source(s):** Authors work




**Source(s):** Authors work

**Figure 2.** The volume of agri-food products produced by farmers

carbon emission in the production process is 9.34 kg-$CO_2$ (29%). The amount of carbon emissions in the distribution process is caused by the use of vehicles that require fuel. The more products shipped, the more fuel is used, which would increase the number of carbon emissions. These findings are relevant to previous research which indicates that the largest producer of carbon emissions along the supply chain is in distribution activities (Bonilla *et al.*, 2015; Gurtu *et al.*, 2017; Li *et al.*, 2022). Furthermore, Aktas and Temiz (2020) found that for agri-food products, production activities are not as much as distribution activities in producing carbon emissions. This is because there are not many machining activities that require fuel in the processing of agri-food products. Thus, the production of carbon emissions is not more than distribution activities.

From the perspective of product types, research results related to this agri-food product produce carbon emissions that are different from other types of manufactured products in the production process. For example, Wakeland *et al.* (2012) found that the carbon emissions in the car manufacturing process are greater than the carbon emissions resulting from the process of sending cars from producers to consumers. This is caused by the process of making products which is very long and requires complicated and lengthy machining processes and other tools, which would require a lot of energy. Wang *et al.* (2021a) also claimed that the carbon emissions generated during the production of machinery products are less than those during the distribution process. The findings of this study, which stated that indicated that distribution processes result in a higher number of carbon emissions have impacted the carbon emission and total costs. Table 6 shows the cost of carbon emissions in the production process of 0.0003% of the total cost, and the cost of carbon emissions for the shipping process is 0.73%. This means that the costs incurred for carbon emissions in the production process are significantly lower than the carbon emission costs in distribution processes. This result is relevant to the discussion by Ilyas *et al.* (2021) who believed that

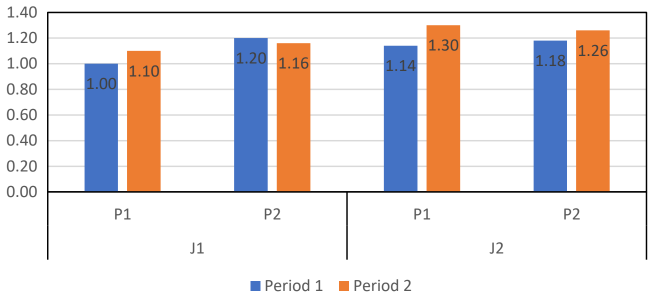



**Figure 3.**
Carbon emission levels of agri-food product processing in Distribution Center

**Source(s):** Authors work

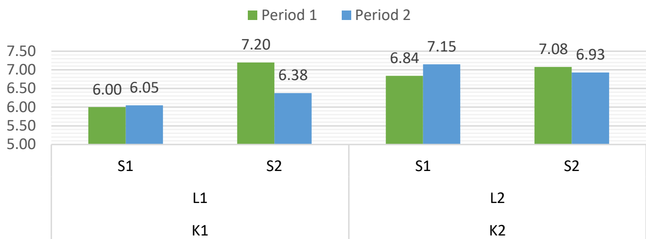



**Figure 4.**
Amount of agri-food waste coming from customers

**Source(s):** Authors work

carbon emission costs contribute considerably to the total costs of distribution. Another study also found that the more frequently product delivered from facilities to other facilities, the more cost of carbon emission incurred (Glock and Kim, 2015; Sopha *et al.*, 2016).

In addition to the cost of carbon emissions, traceability costs are also considered in this production-distribution integration model, which is much higher than the cost of carbon emissions. Costs associated with traceability are directly correlated with production volumes such as tracking and tracings. The movement of agri-food products through the production, supply and distribution stages, is known as traceability costs. Kelepouris *et al.* (2007) indicated that traceability costs are one of the costs involved in the product tracking process both from the point of origin to the point of consumption and the other way around. Traceability costs in the agri-food production process are very important because they are related to the short life of agri-food products. Delays and inaccuracies in tracking and tracing agri-food products would destroy these products and turn them into waste. As is well known, agri-food products cannot be recycled and redistributed for consumption, so product tracking and tracing to find out the speed of delivery and product expiration is an important issue that needs attention. Ramesh and Jarke (2001) revealed that an ideal traceability system consists of a plan that determines the time, place and how the traceability process is built. Traceability in their context refers to monitoring raw materials and food products as they move through the production, inventory and distribution stages.

### *4.6 Sensitivity analysis and managerial implications*

Sensitivity analysis was used to evaluate the solution's effectiveness for the problem parameters and test the robustness of the proposed model results. This study conducted a sensitivity test on several parameters in the proposed model. The parameters carried out by the sensitivity test are the level of production from farmers, the level of consumer demand, the cost of producing agri-food products for farmers, and the percentage of food waste generated by consumers of agri-food products. The analysis is carried out by evaluating how much influence the parameter changes have on the total cost of the developed model. The four-parameter changes are −10%, −5%, +5%, and +10%. The results of the sensitivity analysis test are shown in Table 15 and Figure 5.

Based on Table 15 and Figure 5, it can be seen that changes in the demand level parameter have the most effect on the total cost. This shows that if there is a decrease in demand, the total cost would decrease significantly and vice versa. The second parameter that affects the total cost is the production cost of agri-food products. Parameters of production level and amount of agri-food product waste from consumers have almost the same pattern of changes in total costs.

The development of production and distribution integration in a closed-loop supply chain network by integrating traceability and carbon emissions to provide an overview of policy

| Parameter | Sensitivity | −10% | −5% | 0% | +5% | +10% |
|---|---|---|---|---|---|---|
| Production rate (P) | Total cost ($) | 55.34 | 55.28 | 55.21 | 55.13 | 55.06 |
| | Change in total cost (%) | 0.24 | 0.13 | 0.00 | −0.13 | −0.26 |
| Demand rate (D) | Total cost ($) | 49.54 | 52,373 | 55.21 | 58.04 | 60.31 |
| | Change in total cost (%) | −10.26 | −5.13 | 0.00 | 5.13 | 9.24 |
| Production cost (Cp) | Total cost ($) | 52.29 | 53,747 | 55.66 | 56.66 | 58.12 |
| | Change in total cost (%) | −5.28 | −2.64 | 0.00 | 2.64 | 5.28 |
| Food waste (Wc) | Total cost ($) | 55.13 | 55,168 | 55.24 | 55.24 | 55.28 |
| | Change in total cost (%) | −0.13 | −0.07 | 0.00 | 0.07 | 0.13 |

**Source(s):** Authors work

**Table 15.** Parameter sensitivity test on changes in the total cost

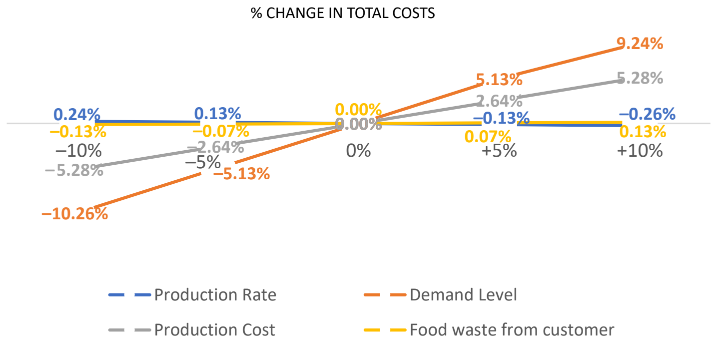



**Figure 5.** Sensitivity test results for the percentage of savings on total costs

**Source(s):** Authors work

recommendations to stakeholders involved in multiechelon and multiperiod supply chains, namely producers, distributors, food waste centers, and of course, the government. Government policies related to carbon emission regulations that focus on environmental issues significantly impact the business world. The regulation of carbon emission taxes issued by the industrial sector encourages the industry to evaluate the production and distribution processes to minimize the carbon emissions produced and correlate with the production and distribution costs incurred by the industry. Touratier-Muller *et al.* (2019) and Renukappa *et al.* (2013) showed that government initiatives are the driving factors for business sectors to reduce carbon emissions in their production and distribution activities. Government participation to take part in efforts to reduce carbon emissions and increase traceability, one of which is by providing logistics infrastructure such as quality roads and Internet networks. A study by Guerrero-Ibanez *et al.* (2015) and Shammar and Zahary (2020) indicated that the logistics infrastructures such as quality roads and Internet networks would affect significantly carbon emission reduction and traceability.

In the context of production, the total cost is affected by the agricultural production process, from seed to harvest. It means that farmers (producers) should optimize the compost of leftover food to help plant growth and, at the same time, reduce unused food waste. Thus, coordination between the food waste collection center (composting center) and the farmers should be developed based on the planting seasons. Sayara *et al.* (2020) show that the right composting time and the correct type of compost would affect the yield of agri-food products. As a result, the findings of the agri-food production-distribution model would impact total reduction costs and decrease the amount of food waste.

This study shows that the highest carbon emission level is generated from shipping agri-food products. Thus, the distribution and transportation sectors should consider implementing an environmentally friendly and sustainable distribution approach. Several approaches can be used, such as the principle of green distribution which can reduce carbon significantly (Klimecka-Tatar *et al.*, 2021). Moreover, the distribution and transportation sectors for agri-food businesses are encouraged to adopt reverse logistics in distribution activities. Semieniuk and Yakovenko (2020) believed that the implementation of the redistribution of recycled products could reduce carbon emissions and increase the company's environmental and financial performance.

## 5. Conclusion and future research

This study has successfully modeled the production-distribution integration model in a closed-loop supply chain of agri-food products by considering the costs of carbon emissions, waste treatment and traceability. The results of this study indicate that the most significant carbon emission comes from distribution activities. Meanwhile, traceability costs are strongly influenced by the number of agri-food products produced, packaged and delivered to consumers. The agri-food waste received by collectors in this model indicated that the wastes from the customer and distribution centers are sent to the composting center to be processed into compost and sent back to the farmer to be used as fertilizer for planting agri-food products. Further research can be developed from the limitations of this research, for example, involving investment costs for land clearing or investment costs in the distribution process. Carbon emissions are limited to carbon emissions in the delivery process from farmers to distribution centers. Further research can calculate the level of carbon emissions in each supply chain involved in the closed-loop supply chain network model. Moreover, this research is also limited to the economic aspect. Further research can integrate aspects of sustainability in the design of the supply chain network. In addition, besides considering the economic aspect, it could also consider environmental and social aspects.

## References

Afra, A.P. and Behnamian, J. (2021), “Lagrangian heuristic algorithm for green multi-product production routing problem with reverse logistics and remanufacturing”, *Journal of Manufacturing Systems*, Vol. 58, pp. 33-43.

Ahumada, O. and Villalobos, J.R. (2009), “Application of planning models in the agri-food supply chain: a review”, *European Journal of Operational Research*, Vol. 196 No. 1, pp. 1-20.

Aktas, A. and Temiz, İ. (2020), “Goal programming model for production-distribution planning by considering carbon emission”, *Gazi University Journal of Science*, Vol. 33 No. 1, pp. 135-150.

Amorim, P., Meyr, H., Almeder, C. and Almada-Lobo, B. (2013), “Managing perishability in production-distribution planning: a discussion and review”, *Flexible Services and Manufacturing Journal*, Vol. 25 No. 3, pp. 389-413, doi: 10.1007/s10696-011-9122-3.

Annosi, M.C., Brunetta, F., Bimbo, F. and Kostoula, M. (2021), “Digitalization within food supply chains to prevent food waste. Drivers, barriers and collaboration practices”, *Industrial Marketing Management*, Vol. 93, pp. 208-220.

Bonilla, D., Keller, H. and Schmiele, J. (2015), “Climate policy and solutions for green supply chains: Europe’s predicament”, *Supply Chain Management: An International Journal*, Vol. 20 No. 3, pp. 249-263, doi: 10.1108/SCM-05-2014-0171.

Costa, C., Antonucci, F., Pallottino, F., Aguzzi, J., Sarriá, D. and Menesatti, P. (2013), “A review on agri-food supply chain traceability by means of RFID technology”, *Food and Bioprocess Technology*, Vol. 6 No. 2, pp. 353-366, doi: 10.1007/s11947-012-0958-7.

de Keizer, M., Haijema, R., Bloemhof, J.M. and van der Vorst, J.G.A.J. (2015), “Hybrid optimization and simulation to design a logistics network for distributing perishable products”, *Computers and Industrial Engineering*, Vol. 88, pp. 26-38, doi: 10.1016/j.cie.2015.06.017.

Domínguez-Caamaño, P., García-Arca, J., Fernandez-González, A.J. and Prado-Prado, J.C. (2017), “Transport KPIs for supply chain improvement. A literature analysis”, *Engineering Systems and Networks: The Way Ahead for Industrial Engineering and Operations Management*, pp. 251-258.

Ech-Charrat, M.R., Amechnoue, K. and Zouadi, T. (2017), “Dynamic planning of reusable containers in a closed-loop supply chain under carbon emission constrain”, *International Journal of Supply and Operations Management*, Vol. 4 No. 4, pp. 279-297.

Farahani, P., Grunow, M. and Günther, H.O. (2012), “Integrated production and distribution planning for perishable food products”, *Flexible Services and Manufacturing Journal*, Vol. 24 No. 1, pp. 28-51, doi: 10.1007/s10696-011-9125-0.

Fleischmann, M., Bloemhof-Ruwaard, J.M., Dekker, R., Van der Laan, E., Van Nunen, J.A. and Van Wassenhove, L.N. (1997), "Quantitative models for reverse logistics: a review", *European Journal of Operational Research*, Vol. 103 No. 1, pp. 1-17.

Gautam, R., Singh, A., Karthik, K., Pandey, S., Scrimgeour, F. and Tiwari, M. (2017), "Traceability using RFID and its formulation for a kiwifruit supply chain", *Computers and Industrial Engineering*, Vol. 103, pp. 46-58.

Glock, C.H. and Kim, T. (2015), "Coordinating a supply chain with a heterogeneous vehicle fleet under greenhouse gas emissions", *The International Journal of Logistics Management*, Vol. 26 No. 3, pp. 494-516, doi: 10.1108/IJLM-09-2013-0107.

Göbel, C., Langen, N., Blumenthal, A., Teitscheid, P. and Ritter, G. (2015), "Cutting food waste through cooperation along the food supply chain", *Sustainability*, Vol. 7 No. 2, pp. 1429-1445.

Guerrero-Ibanez, J.A., Zeadally, S. and Contreras-Castillo, J. (2015), "Integration challenges of intelligent transportation systems with connected vehicle, cloud computing, and internet of things technologies", *IEEE Wireless Communications*, Vol. 22 No. 6, pp. 122-128.

Gurtu, A., Searcy, C. and Jaber, M.Y. (2017), "Emissions from international transport in global supply chains", *Management Research Review*, Vol. 40 No. 1, pp. 53-74, doi: 10.1108/MRR-09-2015-0208.

Handayani, D.I., Masudin, I., Rusdiansyah, A. and Suharsono, J. (2021), "Production-distribution model considering traceability and carbon emission: a case study of the Indonesian canned fish food industry", *Logistics*, Vol. 5 No. 3, p. 59.

Ilyas, M., Yudha, F., Dana Marsetiya, U., Dian Palupi, R. and Evan, L. (2021), "A profit-based model of integrated inventory-production (IPP) considering imperfect quality: a case study of Indonesian food manufacturing industry", *Industrial Engineering and Management Systems*, Vol. 20 No. 3, pp. 412-428, doi: 10.7232/iems.2021.20.3.412.

Jabarzadeh, Y., Reyhani Yamchi, H., Kumar, V. and Ghaffarinasab, N. (2020), "A multi-objective mixed-integer linear model for sustainable fruit closed-loop supply chain network", *Management of Environmental Quality: An International Journal*, Vol. 31 No. 5, pp. 1351-1373.

Jing, Y. and Li, W. (2018), "Integrated recycling-integrated production-distribution planning for decentralized closed-loop supply chain", *Journal of Industrial and Management Optimization*, Vol. 14 No. 2, p. 511.

Kallel, L. and Benaissa, M. (2011), "A production model to reduce batch dispersion and optimize traceability", in *Proceedings of the 2011 4th International Conference on Logistics Hammamet*, Tunisia, 31 May–3 June, pp. 144-149.

Kannan, D., Diabat, A., Alrefaei, M., Govindan, K. and Yong, G. (2012), "A carbon footprint based reverse logistics network design model", *Resources, Conservation and Recycling*, Vol. 67, pp. 75-79.

Kelepouris, T., Pramatari, K. and Doukidis, G. (2007), "RFID-enabled traceability in the food supply chain", *Industrial Management and Data Systems*, No. 107, pp. 183-200.

Klimecka-Tatar, D., Ingaldi, M. and Obrecht, M. (2021), "Sustainable developement in logistic–a strategy for management in terms of green transport", *Management Systems in Production Engineering*, Vol. 29 No. 2, pp. 91-96.

Kresna, B.A., Seminar, K.B. and Marimin, M. (2017), "Developing a traceability system for tuna supply chains", *International Journal of Supply Chain Management*, Vol. 6 No. 3, pp. 52-62.

Li, X., Ouyang, Z., Zhang, Q., Shang, W.-l., Huang, L., Wu, Y. and Gao, Y. (2022), "Evaluating food supply chain emissions from Japanese household consumption", *Applied Energy*, Vol. 306, 118080.

Liu, S. and Papageorgiou, L.G. (2013), "Multiobjective optimisation of production, distribution and capacity planning of global supply chains in the process industry", *Omega*, Vol. 41 No. 2, pp. 369-382.

Mangla, S.K., Luthra, S., Mishra, N., Singh, A., Rana, N.P., Dora, M. and Dwivedi, Y. (2018), "Barriers to effective circular supply chain management in a developing country context", *Production Planning and Control*, Vol. 29 No. 6, pp. 551-569.

Manupati, V.K., Jedidah, S.J., Gupta, S., Bhandari, A. and Ramkumar, M. (2019), "Optimization of a multi-echelon sustainable production-distribution supply chain system with lead time consideration under carbon emission policies", *Computers and Industrial Engineering*, Vol. 135, pp. 1312-1323.

Masudin, I. (2015), "An investigation of the relationship between facility location decisions, service level and distribution costs: a proposed model for Indonesian LPG supply chain", *International Journal of Business and Society (IJBS)*, Vol. 16 No. 1, pp. 117-132.

Masudin, I., Jannah, F.R., Utama, D.M. and Restuputri, D.P. (2019), "Capacitated remanufacturing inventory model considering backorder: a case study of Indonesian reverse logistics", *IEEE Access*, Vol. 7, pp. 143046-143057.

Masudin, I., Ramadhani, A., Restuputri, D.P. and Amallynda, I. (2021), "The effect of traceability system and managerial initiative on Indonesian food cold chain performance: a Covid-19 pandemic perspective", *Global Journal of Flexible Systems Management*, Vol. 22 No. 4, pp. 331-356.

Mawengkang, H. and Mathelinea, D. (2018), "Decision model for planning and scheduling of seafood product considering traceability", *Paper presented at the IOP Conference Series: Materials Science and Engineering*.

Meisel, F., Kirschstein, T. and Bierwirth, C. (2013), "Integrated production and intermodal transportation planning in large scale production–distribution-networks", *Transportation Research Part E: Logistics and Transportation Review*, Vol. 60, pp. 62-78, doi: 10.1016/j.tre.2013.10.003.

Moon, I., Jeong, Y.J. and Saha, S. (2016), "Fuzzy bi-objective production-distribution planning problem under the carbon emission constraint", *Sustainability*, Vol. 8 No. 8, p. 798.

Moniz, S., Barbosa-Póvoa, A.P. and Pinho de Sousa, J. (2013), "New general discrete-time scheduling model for multipurpose batch plants", *Industrial and Engineering Chemistry Research*, Vol. 52 No. 48, pp. 17206-17220.

Moretti, L., Milani, M., Lozza, G.G. and Manzolini, G. (2021), "A detailed MILP formulation for the optimal design of advanced biofuel supply chains", *Renewable Energy*, Vol. 171, pp. 159-175.

Nadal-Roig, E. and Plà-Aragonés, L.M. (2015), "Optimal transport planning for the supply to a fruit logistic centre", *Handbook of Operations Research in Agriculture and the Agri-Food Industry. International Series in Operations Research & Management Science*, Vol. 224, pp. 163-177.

Nair, A. (2005), "Linking manufacturing postponement, centralized distribution and value chain flexibility with performance", *International Journal of Production Research*, Vol. 43 No. 3, pp. 447-463, doi: 10.1080/00207540512331311886.

Osvald, A. and Stirn, L.Z. (2008), "A vehicle routing algorithm for the distribution of fresh vegetables and similar perishable food", *Journal of Food Engineering*, Vol. 85 No. 2, pp. 285-295.

Pishvaee, M.S. and Torabi, S.A. (2010), "A possibilistic programming approach for closed-loop supply chain network design under uncertainty", *Fuzzy Sets and Systems*, Vol. 161 No. 20, pp. 2668-2683.

Piyathanavong, V., Garza-Reyes, J.A., Kumar, V., Maldonado-Guzmán, G. and Mangla, S.K. (2019), "The adoption of operational environmental sustainability approaches in the Thai manufacturing sector", *Journal of Cleaner Production*, Vol. 220, pp. 507-528.

Prashar, A. (2020), "A bibliometric and content analysis of sustainable development in small and medium-sized enterprises", *Journal of Cleaner Production*, Vol. 245, 118665.

Ramesh, B. and Jarke, M. (2001), "Toward reference models for requirements traceability", *IEEE Transactions on Software Engineering*, Vol. 27 No. 1, pp. 58-93.

Renukappa, S., Akintoye, A., Egbu, C. and Goulding, J. (2013), “Carbon emission reduction strategies in the UK industrial sectors: an empirical study”, *International Journal of Climate Change Strategies and Management*, Vol. 5 No. 3, pp. 304-323, doi: 10.1108/IJCCSM-02-2012-0010.

Rong, A. and Grunow, M. (2010), “A methodology for controlling dispersion in food production and distribution”, *Or Spectrum*, Vol. 32, pp. 957-978.

Safaei, A.S., Moattar Husseini, S.M., Farahani, R.Z., Jolai, F. and Ghodsypour, S.H. (2010), “Integrated multi-site production-distribution planning in supply chain by hybrid modelling”, *International Journal of Production Research*, Vol. 48 No. 14, pp. 4043-4069.

Saga, R.S., Jauhari, W.A., Laksono, P.W. and Dwicahyani, A.R. (2019), “Investigating carbon emissions in a production-inventory model under imperfect production, inspection errors and service-level constraint”, *International Journal of Logistics Systems and Management*, Vol. 34 No. 1, pp. 29-55.

Sayara, T., Basheer-Salimia, R., Hawamde, F. and Sánchez, A. (2020), “Recycling of organic wastes through composting: process performance and compost application in agriculture”, *Agronomy*, Vol. 10 No. 11, p. 1838.

Scherhaufer, S., Moates, G., Hartikainen, H., Waldron, K. and Obersteiner, G. (2018), “Environmental impacts of food waste in Europe”, *Waste Management*, Vol. 77, pp. 98-113.

Semieniuk, G. and Yakovenko, V.M. (2020), “Historical evolution of global inequality in carbon emissions and footprints versus redistributive scenarios”, *Journal of Cleaner Production*, Vol. 264, 121420.

Shammar, E.A. and Zahary, A.T. (2020), “The Internet of Things (IoT): a survey of techniques, operating systems, and trends”, *Library Hi Tech*, Vol. 38 No. 1, pp. 5-66, doi: 10.1108/LHT-12-2018-0200.

Shukla, M. and Jharkharia, S. (2013), “Agri-fresh produce supply chain management: a state-of-the-art literature review”, *International Journal of Operations and Production Management*, Vol. 33 No. 2, pp. 114-158.

Solina, V. and Mirabelli, G. (2021), “Integrated production-distribution scheduling with energy considerations for efficient food supply chains”, *Procedia Computer Science*, Vol. 180, pp. 797-806, doi: 10.1016/j.procs.2021.01.355.

Sopha, B.M., Asih, A.M.S., Pradana, F.D., Gunawan, H.E. and Karuniawati, Y. (2016), “Urban distribution center location: combination of spatial analysis and multi-objective mixed-integer linear programming”, *International Journal of Engineering Business Management*, Vol. 8, 1847979016678371.

Thanh, P.N., Bostel, N. and Péton, O. (2008), “A dynamic model for facility location in the design of complex supply chains”, *International Journal of Production Economics*, Vol. 113 No. 2, pp. 678-693.

Touratier-Muller, N., Machat, K. and Jaussaud, J. (2019), “Impact of French governmental policies to reduce freight transportation $CO_2$ emissions on small-and medium-sized companies”, *Journal of Cleaner Production*, Vol. 215, pp. 721-729.

Usman, Y., Fauzi, A., Irawadi, T. and Djatna, T. (2018), “Augmented halal food traceability system: analysis and design using UML”, *Paper presented at the IOP Conference Series: Materials Science and Engineering*.

Verdouw, C., Beulens, A., Trienekens, J. and Wolfert, J. (2010), “Process modelling in demand-driven supply chains: a reference model for the fruit industry”, *Computers and Electronics in Agriculture*, Vol. 73 No. 2, pp. 174-187.

Wakeland, W., Cholette, S. and Venkat, K. (2012), “Food transportation issues and reducing carbon footprint”, *Food Production and Processing. Food Engineering Series*, Springer, Boston, pp. 211-236.

Wang, H., Zhang, H., Hou, K. and Yao, G. (2021a), “Carbon emissions factor evaluation for assembled building during prefabricated component transportation phase”, *Energy Exploration and Exploitation*, Vol. 39 No. 1, pp. 385-408.

Wang, W., Wang, S. and Su, J. (2021b), "Integrated production and transportation scheduling in E-commerce supply chain with carbon emission constraints", *Journal of Theoretical and Applied Electronic Commerce Research*, Vol. 16 No. 7, pp. 2554-2570.

Yadav, D., Kumari, R., Kumar, N. and Sarkar, B. (2021), "Reduction of waste and carbon emission through the selection of items with cross-price elasticity of demand to form a sustainable supply chain with preservation technology", *Journal of Cleaner Production*, Vol. 297, 126298.

Yeh, J.-F., Liu, C.-Y., Chen, T.-H., Yang, H.-T. and Liang, W.-B. (2019), "Intelligent production-distribution system with fish category detection and traceability management", *Paper presented at the 2019 IEEE International Conference on Consumer Electronics-Taiwan (ICCE-TW)*.

Yüksel, H. (2022), "Industry 4.0 transformation: factors affecting adoption and impacts on companies", *International Journal of Industrial Engineering and Operations Management*, Vol. 4 No. 3, pp. 63-89, doi: 10.1108/IJIEOM-06-2022-0020.

Zahedi, A., Salehi-Amiri, A., Hajiaghaei-Keshteli, M. and Diabat, A. (2021), "Designing a closed-loop supply chain network considering multi-task sales agencies and multi-mode transportation", *Soft Computing*, Vol. 25 No. 8, pp. 6203-6235.

Zhang, W. and Wilhelm, W.E. (2011), "OR/MS decision support models for the specialty crops industry: a literature review", *Annals of Operations Research*, Vol. 190, pp. 131-148.

Zhang, Q., Sundaramoorthy, A., Grossmann, I.E. and Pinto, J.M. (2017), "Multiscale production routing in multicommodity supply chains with complex production facilities", *Computers and Operations Research*, Vol. 79, pp. 207-222.

**Corresponding author**
Ilyas Masudin can be contacted at: masudin@umm.ac.id