The Impact of Limited Carbon Emission on Supply Chain and Emission Cost

Thina Ardliana[1,2][a], I Nyoman Pujawan[2][b] and Nurhadi Siswanto[2][c]
[1]*Design and Manufacture Engineering, Shipbuilding Institute of Polytechnic Surabaya, Surabaya, Indonesia*
[2]*Department of System and Industrial Engineering, Sepuluh Nopember Institute of Technology, Surabaya, Indonesia*

Keywords: Carbon Emission Policies, Supply Chain, Inventory.

Abstract: Nowadays, the effects of global warming are at a critical point and have threatened the destruction of the earth's ecosystems. The most dangerous cause of global warming is carbon. This problem seriously forces the countries of the world to focus on reducing carbon emissions. The commitments are binding for all countries, so they have limited CO2. Transportation is one of the largest sources of emissions from activities in the supply chain. The transportation issue should be investigated at the same time inventory decisions are made to minimize supply chain costs. The modes of transport considered in this study are trucks that are distributed from the multi-supplier to the warehouse. The purpose of this model is to observe the impact of the application of carbon emission policies, such as carbon cap (limited) and carbon tax on the decision variables. The changes in the parameters of emissions affect the quantity of emissions, the total cost of the system, and the total cost of emissions.

1 INTRODUCTION

Carbon emission is defined as the number of carbon dioxide gas (CO2) emitted to the air. The carbon emission is also categorized as greenhouse gases (GHGs). The ideal composition of CO2 in the clean air should be at the level of 314 ppm. If the amount of carbon emissions in the atmosphere is too high, it will increase air pollution and cause a greenhouse gas effect (Ardliana, 2020a). The IPCC (2006) stated that GHG emissions increased by 70% between 1970 and 2004 and that the majority of GHG elements are CO2. The increase in GHGs is due to three main sectors: energy, transport, and industry (Ardliana, 2020b). In 2009, the Low Carbon Society (LCS) set a goal of reducing CO2 emissions from 2.9 tons per capita to 0.5 tons per capita by 2050. Therefore, the developed countries and the industrialized countries should reduce their emissions to 0.5 tons per capita by 2050 to offset the increase in CO2 emissions in the last 70 years, which has caused the greenhouse effect.

Not only are the developed countries and the industrialized countries demanded to reduce their emissions, but also to stimulate or support the developing countries that still have tropical forests. Indonesia is one of the countries that could receive this support with compensation for the preservation of its tropical forests on the islands of Sumatra, Kalimantan, Sulawesi, and Papua. Furthermore, tropical and developing countries also could receive additional support or incentives if they can reduce CO2 emissions to 0.5 tons per capita by 2050. In this case, the developed countries committed to utilizing their resources to reduce global CO2 emissions. In previous studies, the relationship between costs and emissions is inversely proportional.

For example, with respect to the carbon cap, the more lenient the carbon limit is given, the lower the cost, but the higher the carbon emissions produced (Ardliana, 2018). Therefore, an optimization between these two variables is necessary to find a compromise or a trade-off. The higher the emissions produced; the more costs are spent reducing them to achieve the theoretical goal: zero-emission. Several regulatory mechanisms have been issued related to carbon emissions policies such as carbon cap (the regulation

[a] https://orcid.org/0000-0002-8349-9462
[b] https://orcid.org/0000-0002-9587-8152
[c] https://orcid.org/0000-0003-1148-9166

Ardliana, T., Pujawan, I. and Siswanto, N.
The Impact of Limited Carbon Emission on Supply Chain and Emission Cost.
DOI: 10.5220/0010944500003260
In *Proceedings of the 4th International Conference on Applied Science and Technology on Engineering Science (iCAST-ES 2021)*, pages 304-308
ISBN: 978-989-758-615-6; ISSN: 2975-8246

of carbon emission capacity permitted by a company). Benjaafar et al. (2010), Hua et al. (2011), and Hammami et al. (2015) carried out an investigation in the inventory area taking into account carbon emission. Furthermore, Hoen et al. (2011), Pan et al. (2013), Jin et al. (2014), and Mohammed et al. (2017) conducted studies on the selection of transportation modes that consider carbon emissions. If the inventory and the transportation mode selection decision are combined and make the carbon emissions as a key consideration, it is expected to minimize costs as well as carbon emissions in supply chain activities (Konur, 2014; Palak et al., 2014; Konur & Schaefer, 2014Tang et al., 2015 and Schaefer & Konur, 2015).

The carbon emission factors are the constraints and the objective function according to the applicable regulations. Benjaafar et al. (2010) contributed to the development of a general and simple optimization model of emissions and total system costs. However, the optimization model did not involve the relationship between inventory and transportation aspects which are important to the model.

Therefore, the purpose of this study is to optimize the total costs associated with transportation and inventory taking into account the carbon limitation and carbon tax. The optimization model is based on the mixed-integer linear programming (MILP) approach.

2 PROBLEM DESCRIPTION

The problem studied is when multi-supplier carries out sales and distribution activities in the form of goods shipped to the warehouse. Transport is very important to be considered because it is proved to have an impact on costs optimization and its emissions. Furthermore, the inventory storage activity also has an impact on costs and emissions. This research uses a single product. The suppliers deliver solid raw materials such as fertilizer and others. Several suppliers send their products to the warehouse.

This condition leads to differences in the total shipping costs and the emissions generated. Each supplier's production capacity is different, resulting in a different number of shipments. It is assumed that the transport capacity of the trucks from the suppliers to the warehouse is the same because they use the same truck. Transportation costs from the suppliers to the warehouse depending on the location between the parties.

The research problem configuration system is illustrated in Figure 1. We address a system consisting of a multi-supplier, (j = 1,2, …, J), and a single-warehouse, W. The suppliers deliver the product to the warehouse. Total demand for the period t is notable. The warehouse also holds inventory. There is initial inventory for each supplier to be zero.

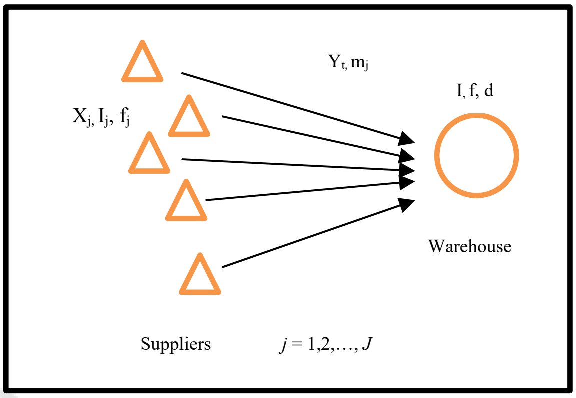

Figure 1: Problem configuration system.

3 MATHEMATICAL MODEL

3.1 Index and Notations

Here we describe the definition of index, parameter and variable for research as follows:

Index

t: Set of planning time horizon [t = 1, 2,…, T]
j: Set of suppliers, [j = 1, 2, 3, …, J]
W: warehouse

Inventory variable

I_{jt} : inventory at the end of period t at supplier j
I_{wt}: inventory on warehouse at the end of t period
$I_{s,t-1}$: inventory at supplier j in previous period t

Delivery variable

y_{jt} :quantity of product delivered to supplier j at planning period t.
x_t : equal to 1 if get the order at period t

Delivery parameter

d_t: total demand quantity at period t
K_w: maximum capacity at a warehouse
Q : vehicle capacity

Carbon emission Parameter

Cap : Emission carbon cap
f_j: fixed inventory carbon emission at the supplier j (in tons)

f_w: fixed inventory carbon emission the inventory at a warehouse (in tons)
m_s: fixed distribution carbon emission from supplier j to a warehouse (in tons)
o_t: fixed order carbon emission (in tons)
$\propto$: coefficient tax of emission cost

Parameters for the objective functions
c_j: transportation cost from supplier j to warehouse
h_j : holding cost at supplier j
h_w: holding cost at a warehouse
p_t: fixed cost

3.2 Model Development

The objective function of this model (1) is to optimize the total costs which are consist of the total cost of inventory at multiple suppliers and a single warehouse, fixed order costs, transport costs, and carbon emission cost. The formulation of the model of this research is given by:

Minimize

$$TC = \sum_{j\epsilon J}\sum_{t\epsilon T} h_j I_{jt} + \sum_{t\epsilon T} h_w I_{wt} + \sum_{t\epsilon T} p_t x_t + \sum_{j\epsilon J}\sum_{t\epsilon T} c_j\, y_{jt} + \propto\left(\sum_{j\epsilon J}\sum_{t\epsilon T} e_j I_{jt} + \sum_{t\epsilon T} e_w I_{wt} + \sum_{t\epsilon T} e_t x_t + \sum_{j\epsilon J}\sum_{t\epsilon T} e_j\, y_{jt}\right) \quad (1)$$

Subject to

$$I_{jt} = I_{j,t-1} + y_{jt} \quad \forall\, t \in T \;\; ,\forall\, j \in J \quad (2)$$

$$I_{jt} \geq 0 \quad \forall\, t \in T \quad (3)$$

$$I_{wt} = I_{w,t-1} + y_{jt} - d_{wt} \quad \forall\, t \in T \;\; ,\forall\, j \in J \quad (4)$$

$$I_{wt} \geq 0 \quad \forall\, t \in T \;\; ,\forall\, j \in J \quad (5)$$

$$\sum_{j\epsilon J}\sum_{t\epsilon T} f_j I_{jt} + \sum_{t\epsilon T} f_w I_{wt} + \sum_{t\epsilon T} o_t x_t + \sum_{j\epsilon J}\sum_{t\epsilon T} m_j\, y_{jt} \leq Cap \quad (6)$$

$$\sum_{j\epsilon J} y_{jt} \leq Q \quad \forall\, t \in T \;\; ,\forall\, j \in J \quad (7)$$

$$y_{jt} \geq 0 \quad \forall\, t \in T \;\; ,\forall\, j \in J \quad (8)$$

$$x_t \in \{0,1\} \quad \forall\, t \in T \quad (9)$$

Constrain are explain with:

(2) the inventory balance at the each supplier.
(3) no shortage at the each supplier.
(4) the inventory balance on warehouse.
(5) to ensure that there is no stock-out at the warehouse.
(6) the limit of carbon emission.
(7) limitation that guarantee the quantity delivered does not exceed the capacity of truck.
(8)-(9) are integrality and non-negativity constraints.

4 DATA EXPERIMENT

In this section, the numerical test was carried out for five suppliers with three time periods to analyze the impact of the carbon policy on the quantity of carbon emission and the total emission cost. Two carbon policies are addressed, namely the carbon cap and the carbon tax. The delivery activity is assumed by the supplier to the warehouse which is far away. The data are given: 1). capacities of each supplier (5000 tons), 2) warehouse capacity (10,000 tons), 3) vehicle capacity (1000 tons). Each supplier produces 1000 tons per period.

The demand for each period is given 900 tons, 900 tons, and 800 tons. The warehouse holding cost is \$0.9 and the holding costs for each supplier are \$0.7; \$0.6; \$0.5; S0.4; and \$0.3. The shipping costs from each supplier to the warehouse are \$1; \$2; \$3; \$4; and \$5. Then we use the carbon emission data such as the carbon tax is \$0.25, while the coefficients of each supplier inventory are \$0.9; \$0.7; \$0.6; \$0.2; and \$0.1. The emission coefficient of warehouse inventory is 0.4 and the truck emission coefficient from each supplier is 0.4; 0.3; 0.2; 0.3; and 0.2. Meanwhile, the fixed order cost emission is \$0.5; \$0.1; \$0.3; \$0.1; and \$0.2.

5 RESULT AND DISCUSSION

5.1 Carbon Cap

In this section, we examined the effect of changing the carbon cap parameter on the total system costs, total emission costs, and the quantity of carbon emission in five scenarios. The impact of this change in carbon cap is seen as its impact on the total supply chain costs (in \$), total emission costs (in \$), and the total amount of emissions generated (in tons). The results of the comparison obtained are shown in Table 1 and Figure 2.

Table 1 and Figure 2 show that five scenarios of carbon cap parameters in the range of 570 to 610 tons are used to analyze the effects on three variables, namely the total cost of the system, the total emission cost, and the quantity of carbon emission. The results show that the more relaxed the allowable carbon emission cap, the lower the total system costs, but will increase the total emission costs and the quantity of emission. As for the carbon cap in the 600 tons scenario, it will produce an optimal solution, as stable as total cost, total quantity, and total emission. This can be seen in the value effect, or the effect is the same if the carbon cap value increases above 600 tons. This shows that there is an optimal solution in the carbon cap number.

Table 1: The effect of the change in carbon cap on total cost, total emission cost, and quantity of carbon emission.

Carbon cap	Total cost of system ($)	Total emission cost ($)	Qty. of carbon emission (tons)
570	52,765.70	142.50	570
580	52,182.05	144.75	579
590	51,598.40	147.00	588
600	50,820.20	150.00	600
610	50,820.20	150.00	600

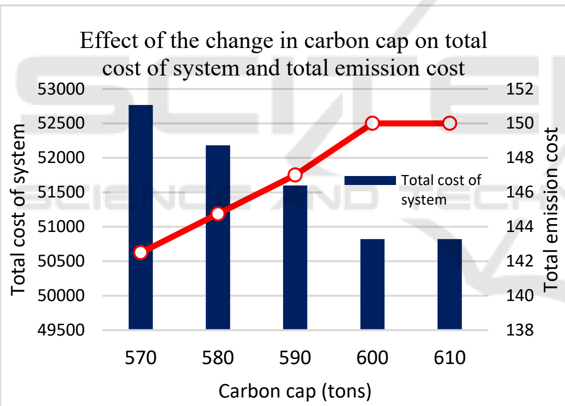

Figure 2: Sensitivity analysis of carbon cap.

5.2 Carbon Tax

Next, the carbon tax parameter is addressed in this study in five scenarios. The value of the carbon cap is set to the optimal solution (600 tons), while the value of the carbon emission tax is changed in the range of $0.15 to $0.55. The impact of this change in the carbon tax is seen as its effect on changes in total supply chain costs (in $), total emission costs (in $), and the total amount of emissions produced (in tons). The following is the result of the comparison is shown in Table 2 and Figure 3.

Table 2 and Figure 3 indicate that increasing the emission tax therefore the total cost and the emission cost increase. However, the impact of the changes in the carbon tax on the total quantity of carbon emission seems to be insignificant (the optimal value remains 600 tons). This is because the carbon tax has an impact on the objective function of this modeling.

Table 2: The effect of the change in carbon tax on total cost, total emission cost, and quantity of carbon emission.

Carbon tax	Total cost of system ($)	Total emission cost ($)	Qty. of carbon emission (tons)
0.15	4,9968.20	90.00	600
0.25	50,820.20	150.00	600
0.35	51,672.20	210.00	600
0.45	52,524.20	270.00	600
0.55	53,376.20	330.00	600

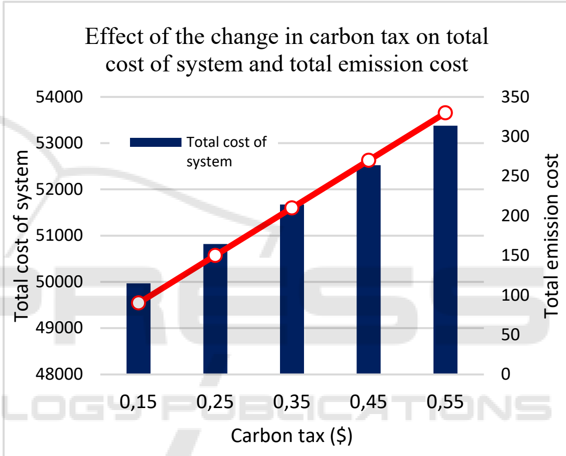

Figure 3: Sensitivity analysis of carbon tax.

6 CONCLUSIONS

This paper investigates the carbon cap and carbon tax for multi-supplier with a single warehouse and multiple periods. This paper develops a MILP model to optimize the carbon emissions and minimize the overall costs of the system. The results obtained from the numerical test show that the more leeway the allowable carbon emission capacity is allowed, the higher the cost of emissions, and carbon generated, but the overall cost of the system decreases.

This indicates that carbon constraints have an impact on the total cost of the supply chain, total emission costs, and the total amount of emissions generated. Meanwhile, the higher the value of the carbon tax imposed, it will burden the total system costs and supply chain emission costs. This research is still limited to a small scale and can then be further developed by comparing it to metaheuristic methods such as the genetic algorithm (GA) and particle swarm optimization (PSO). Further studies may consider multiple distribution centers as well as more complex models with multiple customers.

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