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A Modelling of Multi-Objective Sustainability Palm Kernel Supply Chain Based on Hybrid NSGA-II and Reinforcement Learning

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ABSTRACT

Palm kernel shell supply chain is a partial network of integrated palm oil supply chain network having potential business to be developed in order to reduce waste in the network. Sustainability and uncertainty are important challenges in the supply chain network design to make the business network sustain. This research work aims to design a Strategy of Sustainable Multi-Echelon Supply Chain based on Hybrid NSGA-II and Reinforcement Learning Under Uncertainty in Palm Kernel Shell Material Flow. We design a mathematical model with triple objectives in palm kernel shell supply chain network to meet sustainability criteria with economy, social, and environmental impact from the supply chain. To solve tripe objective function Hybrid NSGA II is designed to reach Pareto optimal solution combined with Reinforcement Learning to reach beneficial solution during optimization processes. The hybrid methodology found 28 alternatives strategy and outperform other method in multi-objective model solution processes. The calculation shows environmental reduction (in kg carbon reduction) to 252 kg and economic impact in complex palm kernel shell supply chain network rather than previous research. The solution also suggests the network configuration fo palm kernel shells material flow.

Key Words: Palm kernel shell supply chain, NSGA II, Reinforcement Learning, Sustainability, Uncertainty.

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1. INTRODUCTION

Palm shells are waste from palm oil processing that has not been utilized optimally. The shell is one source of biomass that can be processed into palm kernel shell charcoal or called Palm Kernel Shell Charcoal (PKSC). PKSC is widely used to make coke and coal. When compared to diesel and coal, these materials require lower costs, have little environmental impact and are abundantly available. Palm shell charcoal is used by the activated carbon industry, briquettes to steel smelting. Activated carbon can be used as a color and odor remover in the beverage industry, oil refining, color and odor cleaning in water treatment, dye removal in the sugar industry, solvent recovery, sulfur removal, toxic gases and gas odors in gas purification, as well as as an additive. Catalyst. Optimal utilization of palm kernel shells into a product with high added value requires sustainable supply chain management with consideration of environmental, economic and social impacts.

The design of sustainable supply chain management to ensure optimal utilization of palm kernel shell waste is a research challenge in the field of palm oil sustainability today. Gatti et al (2019) stated that environmental and socio-economic challenges are important aspects to consider in sustainable palm oil waste processing. Wu et al 2017, stated that optimizing the utilization of palm shell waste into potential products needs to be studied in the form of a chain design flow. supply so that the impact on the environment, social and economic value is optimal. The design of the supply chain for processing waste from the palm oil industry requires determining the type of product that must be produced, actors in the supply chain, value chain flows, economic, environmental and social studies so that business processes run in a sustainable manner. This supply chain sustainability challenge needs attention from industry, government and researchers holistically, namely from an economic, social and environmental approach. The sustainable supply chain approach views business activities from upstream (upstream) to downstream (downstream) as a unit that is interconnected and interacts to achieve the same goal. Research on sustainable supply chain systems is one of the studies that has become increasingly popular in recent years due to sustainability issues in various sectors.

Many researches related to supply chain sustainability have been carried out in the last few decades. Lim and Biswas (2018) investigated the impact of sustainability on the integration of palm oil waste biogas processing with conventional palm oil supply chains. This study claims that the integration of biogas processing with the supply chain can increase the level of sustainability. However, the challenge of the sustainability of waste treatment production is still an aspect that needs to be considered in future research. Hadiguna and Tjahjono (2017) state that performance measurement and optimization of integrated supply chains need to receive important attention in research on supply chain sustainability of palm oil processing. Pacheco et al (2020) and Munasinghe et al (2019) suggest research on the sustainability of palm oil waste processing on aspects of connectivity between actors, value chain flows and system complexity along with their social, economic and environmental impacts. These studies provide insight and an illustration that an integrated design of a sustainable supply chain for waste treatment is important in an effort to improve the sustainability of the palm oil business. Previous studies related to the issue of palm oil sustainability have not carried out research in the field of holistic sustainability on the processing of oil palm shells into a high value-added product. Increasing the added value of palm kernel shells has not been widely carried out, although several previous studies suggest conducting research on various by-products of sustainable palm oil processing. The current condition of processing palm shell waste is limited to boiler fuel and is sold directly in the form of shell exports abroad. So that supply chain design research as a strategic aspect of increasing the added value of palm shells is a novelty and important to research as a contribution to the scientific field of the supply chain of the palm oil industry.

This study aims to design an optimization mathematical model to answer the complex challenges of sustainable supply chain design for products from palm shell processing. This research is part of a dissertation entitled "Design of a Sustainable Palm Oil Shell Agroindustry Supply Chain System Model". The linkage of this seminar paper and the overall dissertation is as one part of the design of a sustainable supply chain flow model (answering objective 3 of the research in the dissertation) for the palm kernel shell agro-industry with an optimization approach in the form of three objectives on each of the conflicting sustainability components. The output of the research in this paper is the result of the calculation of supply chain drivers that can be used as a basis in the design of the palm shell agroindustry supply chain system which can have a positive impact in terms of economic, social and environmental. The novelty claimed in this research is the design of the complexity of the supply chain for sustainable palm kernel shell processing with an analytical quantitative approach that can be used as a reference and development of an intelligent system for the design of the palm kernel shell chain. In addition, the development of the NSGAII-Reinforcement Learning hybrid model is also a method contribution to be used in future reward-punishment optimization-based system development processes. The structure of the writing in this paper is structured as follows, the methodology section will explain the framework for developing a mathematical model of operational research according to Taha (2015) which includes problem definitions in the form of the existing condition of the sustainable supply chain of palm shell products, mathematical models in the form of triple-objective optimization, hybrid development NSGA II-Reinforcement Learning and case studies for model testing are discussed in the next chapter. An important contribution to this research in addition to formulating the problem, the three objectives of the palm shell case are the combination of NSGA-II and Reinforcement Learning (RL). NSGA-II is a more efficient optimization problem solving algorithm to solve multi-dimensional optimization problems (more than 2 goals) and RL with the ability to get optimum benefits from each sustainability aspect decision that will be taken.

2. PROBLEM DEFINITION

2.1 Existing condition of sustainable supply chain system for palm shell processed products

The problem of sustainability in the supply chain has a complexity of main concern, namely the consideration of sustainability aspects consisting of economic, social and environmental. This aspect of complexity is also accompanied by the number of echelons in the supply chain and product diversification that flows along the supply chain from upstream to downstream. The modeling challenge in this research also needs to consider the benefits derived from the 3 aspects of sustainability. Currently, palm kernel shells have limited economic value in export sales by the palm oil processing industry abroad to be processed by destination countries into fuels such as briquettes, activated carbon, to the steel smelting industry. The increase in added value in the country itself is still in the form of small-scale processing into briquettes to reuse as boiler engine fuel (Figure 2). Increasing added value and strengthening the palm shell processing system as palm oil industry waste requires sustainable supply chain management with consideration of environmental, economic and social impacts. The existing condition is depicted in Figure 1.The description of the palm shell supply chain is as follows (modification of Chopra and Meindl (2017).

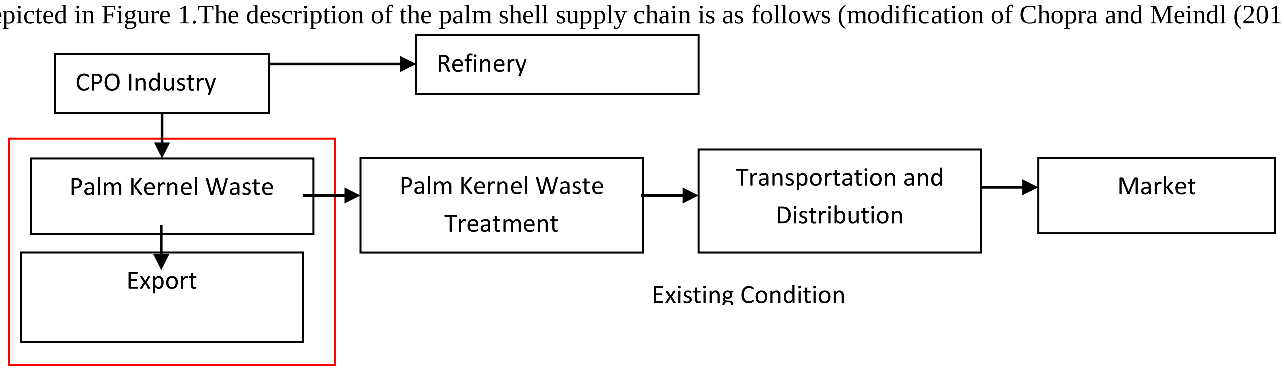

Figure 1. Palm shell processing supply chain flow

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Figure 2. Palm Oil Shells (left) and their derivative products in the form of briquettes (right)

Based on these reasons, this study defines the objectives of the mathematical model of sustainable palm shell supply chain design based on sustainability aspects, namely economic, social and environmental. Specifically, the mathematical model is defined as minimizing the resulting costs as a consideration of the economic aspect, maximizing the positive impact on the environment and social.

The business process model of the palm shell processing industry currently consists of two streams, namely the direct sales flow in the form of palm shells directly exported abroad, and the supply chain flow through processing into products sequentially from the largest to the smallest, namely coal briquettes, charcoal active and bioenergy. Figure 4 describes the business process model of the sustainable supply chain modeling of the palm shell agroindustry studied in this research as a whole. The red line represents the focus of the optimization model of the entire palm shell supply chain system.

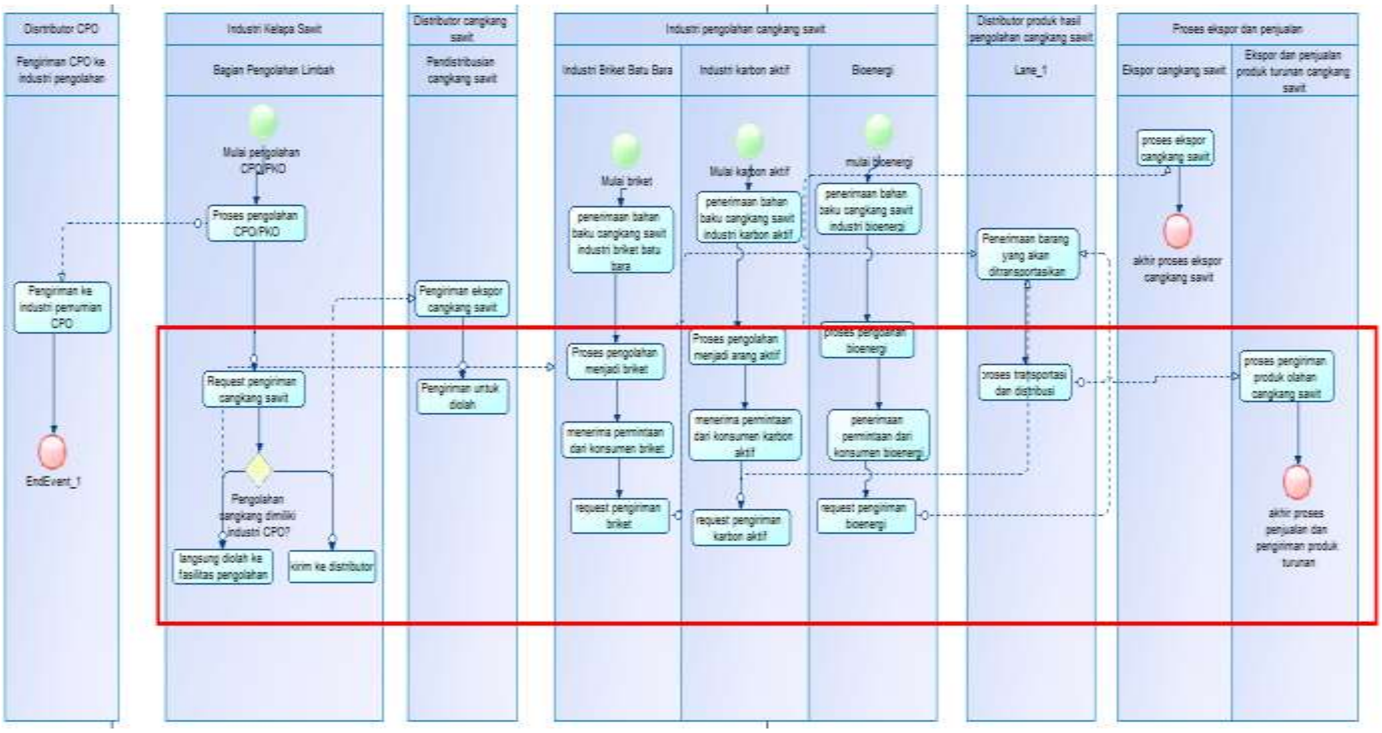

Figure 4. Business process model of sustainable palm shells supply chain

The decisions that should result from the design of the supply chain system are tabulated in Table 1

Table 1. Index and decision variables

Decision variables	Description
$x_{isp}^{sup\rightarrow ind}$	Number of product *i* to be shipped from palm shell supplier *s* to processing industry *p*
$x_{ipr}^{ind\rightarrow tran}$	The number of products *i* that must be delivered by the distribution and transportation center *r* from a given factory *p*
$x_{irm}^{trans\rightarrow mar}$	The number of products *i* that must be delivered by the distribution and transportation center *r* to the market area *m*

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y_{is}^{sup}	The number of product *i* that must be provided by the supplier *s*
y_{ip}^{ind}	The quantity of product *i* that must be produced by industry *p*

The assumptions used in designing the mathematical model are as follows

- Palm shell supply chain design issues depend on the existing capacity constraints (limited facility capacity) of suppliers, processing industries, distribution and transportation centers
- The demand for new products in the palm shell supply chain, the costs and the resulting environmental impact emissions are influenced by the complexity of uncertainty
- Fixed and predetermined facility locations

2.2 Existing condition of sustainable supply chain system for palm shell processed products

The input-process-output of the mathematical model of supply chain optimization for sustainable palm kernel shell processing are as follows (Fan et al 2021; Shirazi et al 2017)

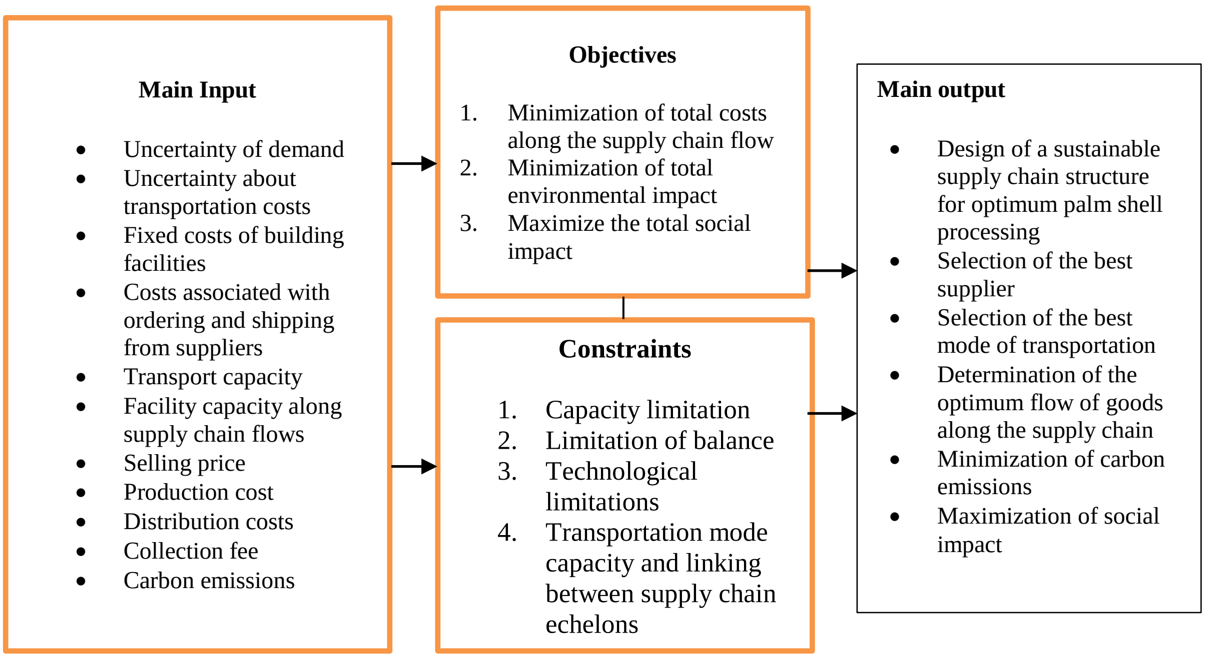

Figure 2. Inputs, objectives, constraints and outputs of the mathematical model

The mathematical model used in this research is triple-objective optimization which consists of 3 objectives with binary, integer and real variables. In general, this mathematical model is defined as follows

$$Maximize/Minimize\ \ (f_1(x,y), f_2(x,y), \ldots., f_k(x,y))$$

3. PROBLEM FORMULATION

The objective function of this mathematical model is to maximize the economic value of the sustainable supply chain of palm shells (Schleifer and Sun 2018), maximize social impacts (Han et al 2020) and minimize the environmental impact calculated from the carbon waste that is reduced if processed into processed palm shell products (Rezk et al 2019; Fauzi 2020). The first objective function is to minimize total cost (maximize profit). The costs (formulation 1) include the costs of cooperation with suppliers, fixed costs of opening a DC Distribution Center, operational costs, transportation costs and costs of purchasing carbon credits. The mathematical model is modified from Nayeri et al (2020). Nayeri et al 2020 modeled a three-goal sustainable supply chain with the definition of the goal of minimizing total costs, social and environmental impacts.

1. Minimization of total costs = Fixed costs of building facilities + Processing and operating costs + Transportation costs – revenue

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2. Minimization of environmental impact = Dust generated in the production process + Dust generated in the repair process + Dust generated in the transportation process + carbon generated from the recovery process
3. Maximization of social impact = Opportunity to generate permanent and contract workers – impact on workforce Health

This model is modified by adopting a theoretical basis for optimizing 3 objectives by adjusting the concept in the case of shells to focus on the strategic design of the palm shell processing supply chain including

1. Goal 2 is specific on reducing carbon from waste processing of palm kernel shells as a material of important concern in processing (20-22 percent of the palm kernel shell material content).
2. Objective 3 focuses on maximizing social impact through the application of labor with the assumption that the company has considered OSH

Based on the reasons above, this study modeled the 3 objectives of the sustainability aspect in the processing of palm shells as follows (Formulation 1)

$$Min\ Z_1 = \gamma^c(\sum_{s} fod_s W_s + \sum_{fe} fo_{fe} Y_{fe} + \sum_{t}\sum_{r} fo_{rt} Y_{rt} + \sum_{isp} pQ_{psi} + \sum_{qn}\sum_{fe} Op_{fe} Q_{fen}^{q} + \sum_{qn}\sum_{fe} Op_{fe} Q_{feu}^{q} + \sum_{r,t,n} hr_{rnt} rem_{rnt} + \sum_{ee} TC_{ee} + \sum_{jk} Q_{jk}^{q})$$

While the second goal is to minimize the environmental impact resulting from the reduced carbon from processing palm shell waste into further derivative products which are defined as follows (Formula 2)

$$Min\ Z_2 = \gamma^l \sum_{s} \lambda\, Q^s$$

The third objective is the maximization of social impact which is defined as new employment opportunities from the development of a sustainable palm shell supply chain (Formulation 3)

$$Max\ z = \gamma^s \sum_{q} NLFY^q$$

The limitations in this modeling are the capacity and location limitations as well as the links between echelons of the palm shell supply chain defined as follows (Formula 4.5)

$$\sum_{psi} Q < Cap$$

5

$$\sum_{ee} X_{ee} < \sum_{ee} Y_{ee}$$

This formulation is integrated with the Bellman equation in Reinforcement Learning which is denoted as to maximize the positive impact of the equation, which is defined as follows (Formulation 6)

$$v_\pi(s) = \mathbb{E}_\pi[R_{t+1} + \gamma v_\pi(S_{t+1}) | S_t = s]$$

Where R is a positive impact of each value of in the equation

4. THE MODEL SOLUTION

NSGA-III is an extension of NSGA-II which was developed by Deb and Jain (2014) to complete optimization solutions for more than two purposes. NSGA-III algorithm is also called Decomposition-based elitist non-dominated genetic sorting algorithm which is used to maintain diversity in solving multi-objective equations for more than two purposes which tends to produce small Pareto diversity. Reinforcement Learning is a type of machine learning algorithm that can make software agents

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and machines work automatically to determine the ideal behavior so as to maximize the performance of the algorithm. This study combines these two approaches to obtain the advantages of each of these methods, namely NSGA-III which is able to provide a better diversity solution on the Pareto front than the NSGA-II version for hypervolume cases such as more than 2 goals (3 goals in this study) (Deb and Jain 2013). As for Reinforcement Learning (RL) combined with NSGA-III in this study to take advantage of RL's capabilities in the form of Reward (Positive impact) and Pinalty (Negative Impact) so that the Pareto front selection process by NSGA-III can provide more results with quality that has an impact positive impact on goal 1 (economic), social (goal 2) and environmental (goal 3) so as to produce a Pareto optimum that can have a positive impact on 3 aspects of sustainability, namely economic, environmental and social. Hybrid NSGA-III and Reinforcement Learning are calculated with the help of java programming software and the help of the Multi-Objective Evolutionary Algorithm (MOEA) framework developed by Hadka (2015). This framework has been tested by Hadka (2015) on more than 1000 cases of multi-objective optimization (Multi-Objective Optimization) mathematical models.

The model solution in this study to solve the optimization case is to use the NSGA-III Decomposition-based elitist non-dominated sorting genetic algorithm which is solved in the Java programming language with the help of the MOEA Framework (Hadka 2019). This NSGA III concept is that the number of reference points is controlled by the number of objectives and division parameters. For an M-objective number, the number of reference points is defined as:

$$H = \binom{M + divisions - 1}{divisions}$$

With the operators as follow

Table 1. NSGA-III parameter values in the MOEA Framework

Parameters	Description	Value
Population size	According to the reference point size divisions H	2
divisions	Size of the number of divisions	1

The MOEA Framework code for the model solution is as follows with a total number of generations 10 000

```
public static void main(String[] args) {
    NondominatedPopulation result = new Executor()
            .withAlgorithm("NSGAIII")
            .withProblemClass(Skenario1.class)
            .withMaxEvaluations(10000)


            .run();
```

Figure 3 MOEA code for NSGA-III

4.1 Case Study and Model Verification

Model testing and verification were carried out to check the validity of the model in terms of the rationality of the output generated during the calculation process. This study uses data collected secondary to several oil palm shell studies to test a three-goal mathematical model on each aspect of sustainability, namely economic, social and environmental, which is presented in the research results section, so as to produce measurable and rational outcomes.

The case study to test the model is with the number of suppliers of palm shells 3, processing industry 3 which consists of the fuel briquette industry, feed and road hardener. Furthermore, two distribution centers and markets were determined, namely industries that utilize processed palm shell products. The data is taken from a crawling website with unknown data because this supply chain design is only predicted to use a random number generation approach according to the distribution of a similar business model.

The calculation results are shown on the Pareto Optima graph with a total of 28 points as follows:

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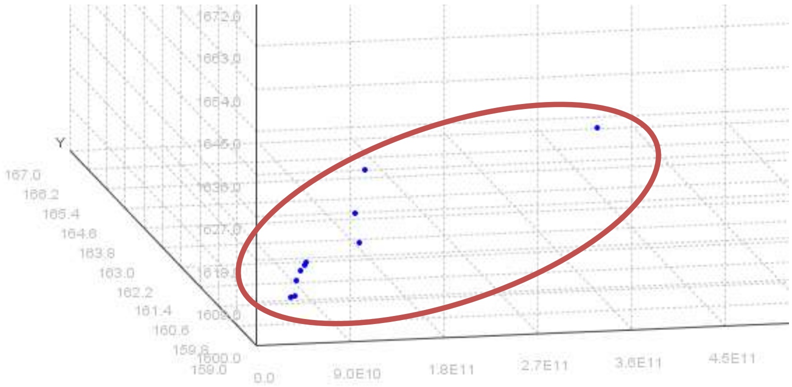

Figure 4. Pareto graph with blue dots are Pareto points

The values for each Pareto point are tabulated in Table 2

Table 2. Values at the Pareto point

No	Objective 1	Objective 2	Objective 3
1	39 175 786 000.00	166.7475	1608.226
2	44 746 093 000.00	161.3679	1608.533
3	50 222 744 000.00	160.9416	1610.56
4	57 165 451 000.00	160.3532	1612.005
5	63 037 182 000.00	159.9537	1612.637
6	65 178 018 000.00	159.7122	1613.093
7	120 926 773 000.00	159.667	1615.532
8	125 646 373 000.00	159.6045	1619.567
9	149 306 032 000.00	159.4614	1625.51
10	381 456 876 000.00	159.2607	1629.816
11	874 507 730 000.00	159.2303	1684.15

The Pareto results in the minimum and maximum values for the optimization case are shown in Table 3

Table 3. Maximum and minimum values of optimization of 3 objectives using NSGA-III

Objectives	Max	Min
Obj 1 (in thousands)	874 507 730	39 175 786
Obj 2 (kg)	166.75	159.23
Obj 3 (people)	1684	1608

The three-objective mathematical model (Formulation 1-6) solved by Hybrid NSGA-III and RL yields 11 Pareto Optimum solutions. When compared with similar research conducted by Nayeri et al 2020. The results of this optimization provide a more diverse Pareto optimum diversity of 11 points (from Table 2). The cost value is smaller, namely a maximum of 874 507 730 and the amount of carbon processed from palm shells more, namely a minimum of 159.23 per day with a maximum total employment of 1 684 and a minimum of 1 608 people. Logically, from the research conducted by Nayeri, the value generated from the calculation of the hybrid NSGA-III and Reinforcement Learning has been verified.

The limitations of this research are as follows

- Unexplained costs at strategic level and design planning for palm shell processing supply chain
- The recommendation for the optimal decision point from Pareto still needs to be selected to support decision making

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5. CONCLUSION

This research has succeeded in modifying the mathematical model of 3-objective optimization to produce a calculation of the decision variables for the design of the palm shell supply chain strategy by considering the sustainable supply chain of processing palm shell waste. The designed model is completed with a proposed new calculation approach, namely hybrid NSGA-III and Reinforcement Learning to maximize the positive impact of supply chain design on sustainable aspects, namely social, environmental and economic. This research is also able to produce Pareto diversity better than previous studies and produce a logical Pareto calculation. This research will continue on the synthesis of the formulation and the development of the selection of the optimum Pareto point for further decision making.

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