Developing a Circular Economy Model by Considering Take-Back Policy, Degree of Innovation, and Market Segmentation with Wolfram Mathematica Cloud Computing

Joni Maulindar
Duta Bangsa University
Surakarta

Nugroho Arif Sudibyo
Duta Bangsa University
Surakarta

Nughthoh Arfawi Kurdhi
Sebelas Maret University

ABSTRACT
According to Bappenas, the problem of electronic waste can be seen as a potential by utilizing supply chain circularity through a refurbishing program that aims to regulate consumption and production patterns sustainably. This research develops several refurbishing models in a circular economy by considering eco-design, distribution channels (manufacturers, retailers, third-party, offline stores, marketplace platforms), and consumer behavior (high-end customers, low-end customers). Based on the existing problems, it is necessary to develop a refurbishing model by considering eco-design, marketing channels, and consumer behavior. This research aims to construct a refurbishing model in a circular economy by considering take-back policies, degree of innovation, and market segmentation. Then determine the optimal solution (policy) from the model. After that, how to apply the model through numerical simulation and sensitivity analysis to see the system behavior.

Keywords
Circular Economy, Take-Back, Degrees of Innovation, Market Segmentation

1. INTRODUCTION
According to Bappenas, the problem of electronic waste can be seen as a potential by utilizing supply chain circularity through a refurbishing program that aims to regulate consumption and production patterns sustainably. This research develops several refurbishing models in a circular economy by considering eco-design, distribution channels (manufacturers, retailers, third-party, offline stores, marketplace platforms), and consumer behavior (high-end customers, low-end customers). The developed model also considers licensing policies, degrees of innovation, cost-sharing mechanisms, government subsidies, take-back policies (collection of used products), in-house and outsourcing policies, quality choice, and product supply constraints.

The purpose of this study is to determine optimal policies for each company to maximize profits and minimize environmental impacts. The model obtained consists of several non-linear functions with inequality constraints. Therefore, the Lagrange method, Karush-Kuhn-Tucker (KKT), can be used to determine the optimal values of decision variables and guarantee maximum profit conditions. Stackelberg, Backward Induction, Nash-Equilibrium, and Shapley-Value methods are used to link optimal policies between the companies involved, including profit and cost-sharing.

As one of the largest consumers of electronics in the world, Indonesia produced 5.1 kg per capita of electronic waste in 2010 and is expected to increase to 8.62 kg per capita in 2030. To overcome this, the National Development Planning Agency (Bappenas) together with the United Nations Development Program (UNDP) has developed an evaluation of the implementation of a circular economy in Indonesia.

Based on existing problems, it is necessary to develop a refurbishing model by considering eco-design, marketing channels, and consumer behavior. In this way, it is hoped that joint optimal policies will be produced so that production and supply chain operations in the refurbishing system can run well with maximum profits and minimum environmental impact without neglecting the quality of service to consumers. This research focuses on superior research on "human development and national competitiveness" with research on the development of "infrastructure, transportation, and defense and security technology". Supply chain management, especially in refurbishing and circular economy activities, has become a way to influence competitiveness to improve company performance. This will force supply chain management to become more responsive, so that it is expected to respond quickly, effectively, and efficiently to changes in the market. A quality supply chain will increase the company's competitive ability as well as consumer satisfaction, thereby encouraging increased competitiveness and growth of the national industry. A successfully implemented supply chain strategy requires appropriate financial (price), production, cooperation, and distribution management.

In 2021, Wang et al. [1] developed a refurbishing model using consideration of the application of the ecodesign concept. Ecodesign is defined as the development of new products by applying environmental aspects to the product design, such as using environmentally friendly materials and technology, low-emission gases, and certain designs so that the product is easy to reproduce over and over again [2]. The demand function in research [1] uses the level of consumer willingness to pay (WTP) without any distribution channels, market segmentation, and cannibalization effects. In implementing the concept of ecodesign and responsibility transfer, there is a financial policy from the government that refers to the research of Chang et al. [3]. In 2020, He et al. [4] conducted research on the influence of quality choice in new products on refurbishing policies.

Furthermore, 2021, Chen et al. [5] developed a refurbishing model carried out by manufacturers and retailers by considering process innovation and cost-sharing mechanisms. Meanwhile, refurbishing is often carried out by other parties such as retailers or third parties [6].

Gaur et al. [7] state that the refurbishing process can be carried out alone (in-house) or with collaborative partners (outsourcing) to be involved in collecting, reprocessing, and remarketing products. Referring to Wang et al. [8], there are two types of licensing policies that third parties can choose, namely fixed fee licenses and royalty fee licenses. The fixed fee licensing policy states that the OEM charges a fixed fee, namely the amount of the cost of the \textit{refurbished} product to the 3P. According to Segetlija et al. [9] distribution channels are a route for goods or services to travel from producers to consumers through marketing intermediaries. Two distribution channels are considered in this research, namely direct distribution channels and indirect distribution channels. Direct distribution channels are when 3P sells products directly to consumers. Meanwhile, distribution is indirect when 3P sells refurbished products at wholesale prices to resellers, who then sell the products to consumers.

In 2011, Ovchinnikov [10] conducted research on OEM strategies for selling new and refurbished products by considering consumer behavior. Then in 2022, Kurdhi et al. [11] analyzed the optimal pricing of refurbished products with the influence of market segmentation and cannibalization effects. Kurdish et al. [11] divide the market into two segments, namely high-end customers (consumers who focus on product quality) and low-end customers (consumers who focus on product price). In their research, Kurdhi et al. [11] also consider consumable product supply constraints, where not all of these products can be collected easily or do not meet the specified quality standards.

For the refurbishing business to continue running, take-back activities or collecting used products are needed. Take-back activities can be carried out directly by the manufacturer and then reprocessed through in-house refurbishing. In 2018, Liu et al. [12] developed a refurbishing model by considering roof policy in marketing refurbished products and its impact on company profits and the environment. Roof policy is a managerial decision regarding the marketing structure of different products and has a significant impact on company performance [13]. In Liu et al.'s model. [12], take-back activities are carried out from consumers to producers and in-house refurbishing is implemented. Meanwhile, in Qian et al. [14], a scenario is applied where take-back and refurbishing are handed over to other parties (outsourcing).

This research aims to construct a refurbishing model in a circular economy by considering take-back policies, degree of innovation, and market segmentation. Then determine the optimal solution (policy) from the model. After that, how to apply the model through numerical simulation and sensitivity analysis to see the behavior of the system.

The circular economy model has been studied in various countries. Even in developed countries, this model has been used in stock modeling. Not only applied but this model is also still undergoing development [15]. Therefore, we want to develop a Circular Economy Model in Indonesia which has never been studied before.

2. RESEARCH METHODS

The research steps are schematically shown in Figure 2. To obtain the latest information and according to research needs, various related literature will be reviewed to see research developments and identify problems. In addition, refurbishing formulations in the circular economy are developed based on research problems identified from real-life systems. Therefore, observations of the supply chain system in the field need to be carried out to determine the real condition of the system. This research was conducted from the point of view of OEMs, retailers, and third parties, so one of the performance measures chosen was the total profit of each company in the supply chain. Factors that influence performance measures will be considered in the system modeling step. The development of a mathematical model is carried out by proposing several alternative models so that the model that is most relevant to the real world can be selected.

Optimization techniques are used to obtain optimal solutions which are the basic policies in production and inventory control. In the optimization process, propositions and theorems will be developed as a basis for developing solution methods and algorithms. Completion approaches to models include several methods for mathematical programming with constraints. For more complex models, a heuristic and numerical solution method will be developed by looking at the optimal solution pattern. This approach is used if optimization methods cannot be applied to solving the model. Furthermore, some numerical examples with Mathematica 12.0 software are given to provide a good understanding of the model's behavior and for comparative studies with the results of previous studies. Sensitivity analysis through variations in the value of the model parameters was also carried out to see the significance of the influence of these parameters on performance measures.

The model that has been analyzed is then validated. If the model obtained is not valid, then the model is changed according to the results of the analysis. Valid models can be used as a solution to problems in the field. Furthermore, conclusions are given as an overview of the research results that have been obtained and discuss several topics of further research.

In this study, the optimal completion of the model was obtained using the Karush-Kuhn-Tucker (KKT) and Stackelberg methods. The KKT method is an optimization technique that can be used in finding the optimum point of a constrained function regardless of linear or non-linear. Stackelberg is one of the non-cooperative game-solving strategies in game theory. In Stackelberg, there are two companies as players, namely one company acting as a leader and one company acting as a follower. Companies that act as leaders have the authority to determine in advance the quantity of output to be produced to obtain maximum profit. Based on the amount of output that has been determined by the leader, followers will react according to the provisions that the leader will not change the level of output. This model assumes that decision-making is done sequentially. The Stackelberg model can be solved to obtain the subgame perfect Nash equilibrium (SPNE), which is a strategy profile by each player taking into account the strategies of other players and requires each player to play in a Nash Equilibrium in every subgame.

Suppose the leader is a producer and the follower is a retailer. Producers will determine wholesale prices (w_r) or license fees (f) and then retailers will react by setting a selling price of p_r. Consumer demand at price p_r is $D(p_r)$, so the retailer will respond as much as q_r to the refurbishing agent. To determine the subgame perfect Nash equilibrium is done through backward induction.

3. RESULTS AND DISCUSSION

In this research, the Retailer Remanufacturing model will be solved by cloud computing. The cloud computing used is Wolfram Mathematica. Figure 1 is the User Interface of Wolfram Mathematica.

The first step in this research is the optimal solution (Stackelberg Game). Figure 2 is the output from Mathematica cloud computing which has been run to determine the optimal solution (Stackelberg Game). To obtain the optimal solution, the concept of derivatives is used in the process.

The second step of this research is to determine the optimal number of Retailer Remanufacturing models. Figure 3 is the output of Mathematica cloud computing that has been run to determine the optimal number of Retailer Remanufacturing models.

After determining the optimum amount to be produced, the next step is to substitute the optimum amount to obtain maximum profit from the model. Figure 4 is the output of Mathematica cloud computing that has been run to determine the maximum profit from the Retailer Remanufacturing model.

From the research that has been carried out, it turns out that Wolfram Mathematica cloud computing can complete a Retailer Remanufacturing model. These results have been checked using the Wolfram Mathematica installer software and calculated manually.

With Wolfram Mathematica cloud computing, it certainly makes it easier to complete a distribution model. Wolfram Mathematica cloud computing does not need to be installed on a laptop and only requires a browser and internet connection. The calculation results obtained by cloud computing are of course also accurate, this has been proven by the author in the Retailer Remanufacturing model.

The Retailer Remanufacturing model that has been calculated will certainly be a recommendation for business actors in the world of work. This is in line with research conducted by (Desi Triana Putri & Muhammad Subhan, 2023).

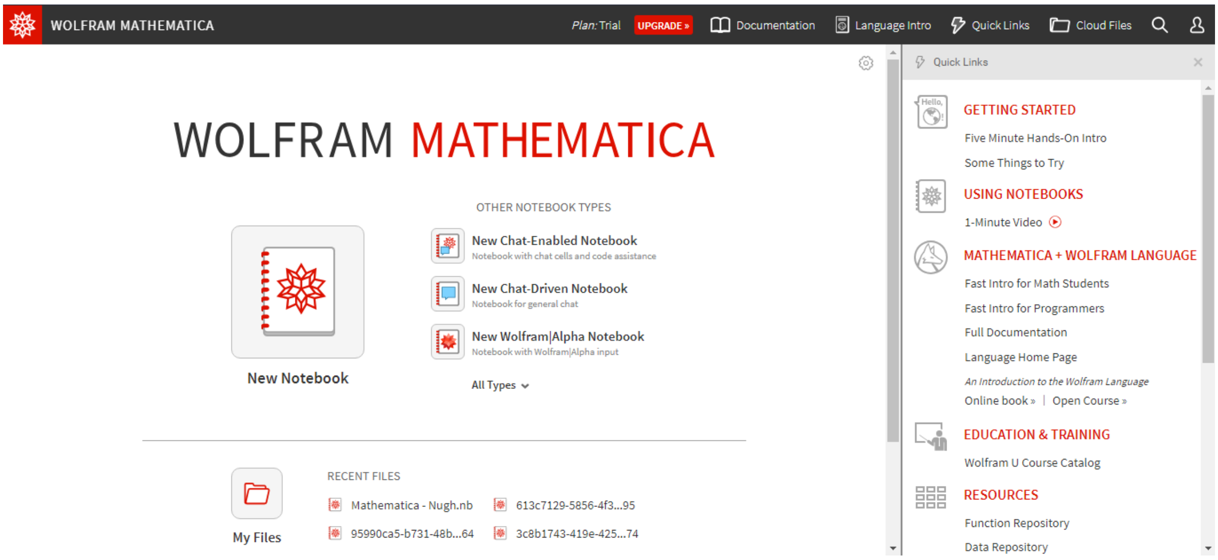

Fig 1. Initial view of Wolfram Mathematica cloud computing

```
Penyelesaian Optimal (Stackelberg Game) y
Retailer
In[•]:= f[x_, y_] := (x - wn) (q - b (x - y)) + (y - cr) (a - l y + b (x - y))
In[•]:= system1 = {D[f[x, y], x] == 0, D[f[x, y], y] == 0} // Simplify;
In[•]:= FullSimplify[Solve[system1, {x, y}]]
Out[•]= {{x → (a b + (b + l) q + b l wn)/(2 b l), y → (a + cr l + q)/(2 l)}}
{{x → (a b + (b + l) q + b l wn) / (2 b l), y → (a + q + l cr) / (2 l)}}
x → (a b + (b + l) q + b l wn) / (2 b l)
y → (a + q + l cr) / (2 l)
Manufacturer
M = (wn - (1 - e αn) cn) (q - b (pn - pr)) - k e2
In[•]:= g[z_] := (z - (1 - e αn) cn) (q - b ((a b + (b + l) q + b l z) / (2 b l) - (a + q + l cr) / (2 l))) - k e2
In[•]:= FullSimplify[Solve[g'[z] == 0, {z}]]
Out[•]= {{z → (q + b (cn + cr - cn e αn))/(2 b)}}
```

Fig 2. The optimal solution for Retailer Remanufacturing

```
Quantity Optimal

qn = q - b (pn - pr)

In[•]:= FullSimplify[q - b ((2 a b + 2 b q + 3 l q + b l (cr + cn (1 - e αn))) / (4 b l) - (a + q + l cr) / (2 l))]

Out[•]= 1/4 (q + b (cr + cn (-1 + e αn)))

qr = a - l pr + b (pn - pr)

In[•]:= FullSimplify[a-l((a+q+l cr)/(2 l))+b((2 a b+2 b q+3 l q+b l (cr+cn (1-e αn)))/(4 b l)-(a+q+l cr)/(2 l))]

Out[•]= 1/4 (2 a - 2 cr l + q - b (-cn + cr + cn e αn))
```

Fig 3. Optimal number of Retailer Remanufacturing models.

```
(wn - (1 - e αn) cn) (q - b (pn - pr)) - k e2

In[•]:= FullSimplify[(((q + b cr + cn (b - b e αn)) / (2 b)) - (1 - e αn) cn) (q - b ((2 a b + 2 b q + 3 l q + b l (cr + cn (1 - e αn))) / (4 b
        l) - (a + q + l cr) / (2 l))) - k e2]

Out[•]= (-8 b e2 k + q^2 + 2 b q (cr + cn (-1 + e αn)) + b^2 (cr + cn (-1 + e αn))^2) / (8 b)

R = (pn - wn) (q - b (pn - pr)) + (pr - cr) (a - l pr + b (pn - pr))

In[•]:= FullSimplify[((2 a b + 2 b q + 3 l q + b l (cr + cn (1 - e αn))) / (4 b l) - (q + b cr + cn (b - b e αn)) / (2 b)) (q - b ((2 a b + 2 b q + 3 l q +
        b l (cr + cn (1 - e αn))) / (4 b l) - (a + q + l cr) / (2 l))) + ((a + q + l cr) / (2 l) - cr) (a - l ((2 a b + 2 b q + 3 l q + b l (cr + cn
         (1 - e αn))) / (4 b l)) + b ((2 a b + 2 b q + 3 l q + b l (cr + cn (1 - e αn))) / (4 b l) - (a + q + l cr) / (2 l)))]

Out[•]= (4 a^2 b + l (6 cr l - 5 q) q + b^2 l (cr + cn (-1 + e αn))^2 + 2 b (cr^2 l^2 - 2 cr l q + 2 q^2 - cn l (cr l - 2 q) (-1 + e αn)) + 2 a (-3 l q + b (-3 cr l + 4 q +
        / (16 b l)
```

Fig 4. Maximum profit from the Retailer Remanufacturing model.

An economic system or model known as a "circular economy" seeks to minimize the harm that a linear economic strategy does to society and the environment while promoting economic growth by extending the useful life of goods, materials, and resources. A circular economy covers a wide range of actions in all economic sectors, including resource efficiency and carbon emission reduction, in addition to discussing improved waste management through increased recycling.

Future industries and the economy will focus on repairing, reusing, remanufacturing, and recycling rather than just managing raw materials into finished products for consumption. This approach, known as the "Circular Economy," aims to reduce waste production and resource use while also promoting consumption and repair without negatively impacting the environment.

To minimize the quantity of waste materials that are not used and end up in landfills, the circular economy maximizes the utility and added value of raw materials, components, and products. The act of implementation itself may promote more rapid growth in the green economy.

The circular model that has been produced provides recommendations for the optimal number of retailer remanufacturing and the maximum profit that can be obtained. This is in line with research conducted by Roqip 2023 (see [16]). Hopefully, the model that has been produced can be applied to industry. Because the circular model is increasingly being applied to various sectors.

Completion of this circular model uses cloud computing-based Mathematica Wolfram. The resulting solution is an optimal result. With proven methods (see [11]).

In general, cloud computing focuses on the preparation of mathematical models and numerical solution techniques as well as the use of computers to analyze and solve scientific problems. In practical use, it usually takes the form of applying computer simulations or various other forms of computing to solve problems in various scientific fields, but in its development, it is also used to discover new fundamental principles in science.

4. CONCLUSION

The results of this research show that maximum quantity (see Fig 3) and maximum profit (see Fig 4) can be obtained from the Retailer Remanufacturing model. Hopefully, the model that has been produced can be applied to industry. Because the circular model is increasingly being applied to various sectors.

5. ACKNOWLEDGMENTS

Thank you to the Institute for Research and Community Service (LPPM) Duta Bangsa University, Surakarta, which has funded this community service so that it can be carried out well.

6. REFERENCES

[1] S. Wang, X. Y. Chang, and X. Huang, "Effect of the Fund Policy in a Remanufacturing System considering Ecodesign and Responsibility Transfer," Math Probl Eng, vol. 2021, 2021, doi: 10.1155/2021/2429714.

[2] J. Cheng, B. Li, B. Gong, M. Cheng, and L. Xu, "The optimal power structure of environmental protection responsibilities transfer in remanufacturing supply chain," J Clean Prod, vol. 153, pp. 558–569, 2017, doi: 10.1016/j.jclepro.2016.02.097.

[3] X. Chang, J. Wu, T. Li, and T. J. Fan, "The joint tax-subsidy mechanism incorporating extended producer responsibility in a manufacturing-recycling system," J Clean Prod, vol. 210, pp. 821–836, 2019, doi: 10.1016/j.jclepro.2018.10.300.

[4] W. He, L. Liang, and K. Wang, "Economic and environmental implications of quality choice under remanufacturing outsourcing," Sustainability

(Switzerland), vol. 12, no. 3, pp. 1–18, 2020, doi: 10.3390/su12030874.

[5] H. Chen, Z. Dong, G. Li, and K. He, "Remanufacturing process innovation in closed-loop supply chain under cost-sharing mechanism and different power structures," Comput Ind Eng, vol. 162, no. April 2020, 2021, doi: 10.1016/j.cie.2021.107743.

[6] M. Reimann, Y. Xiong, and Y. Zhou, "Managing a closed-loop supply chain with process innovation for remanufacturing," Eur J Oper Res, vol. 276, no. 2, pp. 510–518, 2019, doi: 10.1016/j.ejor.2019.01.028.

[7] J. Gaur, M. Amini, and A. K. Rao, "Closed-loop supply chain configuration for new and reconditioned products: An integrated optimization model," Omega (United Kingdom), vol. 66, pp. 212–223, 2017, doi: 10.1016/j.omega.2015.11.008.

[8] J. Wang, X. Wu, and V. Krishnan, "Manufacturing & Service Operations Management Decision Structure and Performance of Networked Technology Supply Chains Decision Structure and Performance of Networked Technology Supply Chains," no. September, pp. 0–18, 2017.

[9] Z. Segetlija, J. Mesarić, and D. Dujak, "Importance of Distribution Channels," Marketing Channels - for National Economy, pp. 785–809, 2011.

[10] A. Ovchinnikov, "Revenue and cost management for remanufactured products," Prod Oper Manag, vol. 20, no. 6, pp. 824–840, 2011, doi: 10.1111/j.1937-5956.2010.01214.x.

[11] [N. A. Kurdhi, S. S. Dabadghao, and J. C. Fransoo, "Revenue management in a refurbishing duopoly with cannibalization," Journal of Operations Management, no. July, pp. 1–15, 2022, doi: 10.1002/joom.1208.

[12] Y. Liu, Y. Cheng, H. Chen, S. Guo, and Y. Lu, "Selling remanufactured products under one roof or two? A sustainability analysis on channel structures for new and remanufactured products," Sustainability (Switzerland), vol. 10, no. 7, 2018, doi: 10.3390/su10072427.

[13] X. Zhang and Y. Cao, "Selling Vertically Differentiated Products under One Roof or Two? A Signaling Model of a Retailer's Roof Policies," Journal of Retailing, vol. 90, no. 4, pp. 538–551, 2014, doi: 10.1016/j.jretai.2014.09.001.

[14] Z. Qian, J. Chai, H. Li, W. Yan, and H. Chen, "Should OEMs outsource remanufacturing to retailers?," Asia-Pacific Journal of Operational Research, vol. 37, no. 5, 2020, doi: 10.1142/S0217595920500177.

[15] Desi Triana Putri and Muhammad Subhan, "Model Matematika Produksi Persediaan Dengan Adanya Kerusakan Barang Dan Mempertimbangkan Pengurangan Harga Serta Penundaan Pembayaran," Journal Of Mathematics UNP, vol. 8, no. 1, pp. 64–72, Mar. 2023.

[16] Imam Roqip and Farida Ardiani. Inventory and Demand of Goods Android-based: Rest API Implementation on Information System. International Journal of Computer Applications 185(41):45-52, November 2023.