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An Integrated Business Model Based on Linear Programming for Carrageenan Production Chain in Coastal Village

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Abstract. The blue economy concept is a development program that harmonizes economic growth, social equity, and a sustainable environment. In coastal villages, economic growth could be promoted by selecting a high-value and competitive local-based product, selecting a clean production process with renewable energy, proper waste management, and involving people who live in the coastal area. The research is carried out in Padike village, Talango district, Poteran island, Sumenep, East of Java supported by the vocational high school in Padike and the University of Wiraraja, Sumenep as a partnership institution, and involving people living in Poteran island. An integrated business model based on linear programming was designed to perform a carrageenan production chain that consists of modern seaweed cultivation farming, a high-quality seaweed drying dome, a clean carrageenan processing shop with zero waste management, and clean renewable energy. The model developed based on linear programming was run into 2 different scenarios. The first scenario focuses on the optimization in each production station and the second scenario focuses on the carrageenan production itself. From the different scenarios, we obtained that the second scenario resulted in an appealing opportunity. As a result, an integrated business model for managing the carrageenan production chain has been initiated, and as a practical example of the blue economy model which ensures the proper balance between economic growth, social equity, and a sustainable environment.

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1 Introduction

The blue economy concept is a development program that harmonizes economic growth, social equity, and a sustainable environment. In coastal villages, economic growth could be promoted by selecting a high-value and competitive local-based product, selecting a clean production process with renewable energy, proper waste management, and involving people who live in the coastal area and utilizing clean and renewable energy. To promote this concept, a competitive product of seaweed, and the Padike Village, Poteran Island, Sumenep, East Java was selected as a pilot project of the blue economy model.

Euchema cottonii seaweed has various advantages such as easy to cultivate, short cultivation period, low operational cost, environment-friendly process, and easy to market. Seaweed is a type of algae marine plant, a type of multi-cellular algae of the *Thallophyta* division group. The use of seaweed as foodstuffs, cosmetics, and traditional medicines has long been known by the community, while its use as an industrial material that allows it to be exported or even as an alternative energy material has only been developed in recent years [1].

Carrageenan is a compound that belongs to the galactose polysaccharide group extracted from seaweed. Most carrageenan contains sodium, magnesium, and calcium that can be bound to the sulfate ester group of galactose and the 3,6-anhydro-galactose copolymer. Carrageenan can be extracted from seaweed protein and lignin and can be used in the food industry because of its gel-like characteristics, thickening properties, and stabilizing the main material. K-carrageenan is mostly extracted from the red algae *Kappaphycus alvarezii*, known as *Eucheuma cottonii*, while ι-carrageenan is produced from *Eucheuma denticulatum*, also known as *Eucheuma spinosum*. λ-carrageenan is obtained from seaweeds in the genera *Gigartina* and *Chondrus*. Carrageenan comprises up to 50% of the dry weight of seaweed. Carrageenan yield depends on the seaweed cultivation method, seaweed age (harvest time), seaweed post-harvest handling including storage and distribution, and extraction method.

This research is intended to develop an integrated business model based on linear programming, that designs a productive and optimum interaction among all stations up-down stream of seaweed production chain in a coastal community. The production chain starts with seaweed cultivation farming, seaweed drying dome, and carrageenan processing shop and is supported by clean renewable energy.

2 Methodology

Seaweed commodities contribute high economic value both to the domestic economy and as export commodities. According to BPS data, the total production of East Java seaweed in 2019 was 686,203 tons spread across several regencies such as Pacitan, Situbondo, Banyuwangi, Sumenep, Pasuruan, Pamekasan, Lamongan, and Sidoarjo [2]. In Figure 1 we can see that the production of seaweed in Sumenep regency reached 569,000 tons/ year, with the total 58,000 ton production in Poteran island. The cultivation method is commonly using floating cage and the production time can reach 5 times production cycle in a year. The volume of exported seaweed in 2020 was 195,574 tons with a value of USD279.58 million, and in 2021 it increased to 225,612 tons with a value of USD345.11 million. The value of the commodity of dry seaweed is Rp. 20,000/kg while for carrageenan around Rp. 245,000/ kg. With a considerable price difference, further processing of seaweed into carrageenan products is an attractive program to be developed. The summary of the research methodology can be seen in Figure 2.

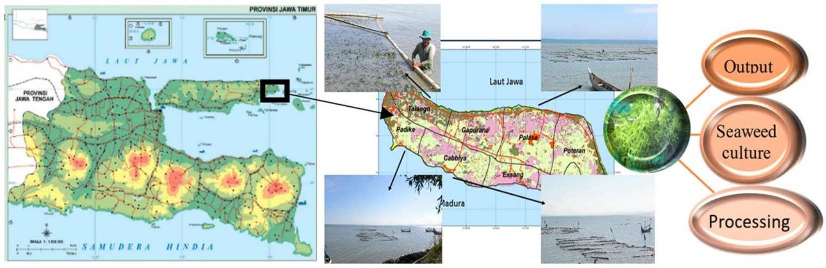

Fig. 1. Seaweed Culture in Poteran Island, Sumenep, Madura

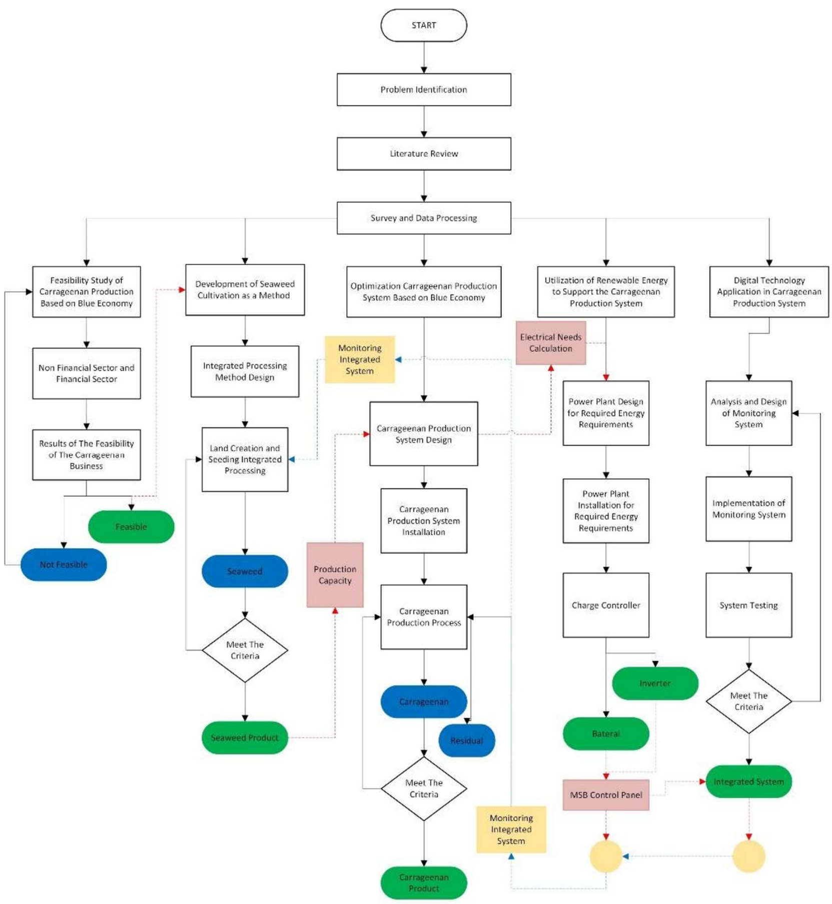

Fig. 2. Research Methodology

2.1 Station 1 – Seaweed Cultivation Farm

In seaweed cultivation farming, season time, a coastal area with suitable current, wave, tidal, sedimentation, and high-quality seawater, and the cultivation method used are very important to the output quality. Improper methods can result in decreased production and less optimal seaweed quality [3]. Two methods commonly used in seaweed cultivation are the monoline/ longline buoyancy method where seaweed is allowed to be in seawater all day, and the fix-off bottom/ bottom culture method allows seaweed to be exposed to air longer at low tide. These methods have their advantages and disadvantages, therefore, the appropriate method of culture should be considered with environmental conditions and the intended product. Seaweed cultivation farming will be monitored following ecosystem characteristics which then, influence the seaweed productivity growth and quality of product as required by the carrageenan processing shop.

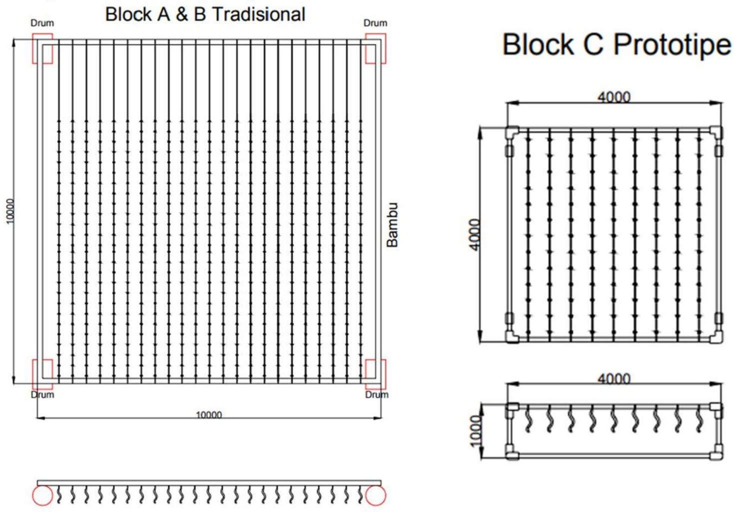

Fig. 3. Design of Seaweed Culture with Floating Cage

The floating cage design of seaweed culture in Figure 3, must be able to hold at least 75 kg of seaweed products. This 75 kg is equivalent to the weight of the crop for one stretch of rope. The design is planned in 2 forms of cultivation scenarios, including (1) the first scenario is chosen by designing a floating cage divided into 2 (two) sub-modules, namely the basic sub-module and the upper sub-module. Both sub-modules can be worked together or in series, after both sub-modules are completed they can be assembled into modules, while (2) the second scenario is chosen by designing a floating cage divided into 4 (four) sub-modules, namely the front, back, left and right sub-modules. The right sub-module is assembled into the rear sub-module, then assembled into the left sub-module to form a sub-module resembling the letter U, and finally the front sub-module is assembled into a U-shaped sub-module.

2.2 Station 2 – Seaweed Drying Home

Traditionally, people dry seaweed openly with hot sunlight, requiring between 6-10 days and according to the Indonesian National Standard (SNI-2354-2-2015) for 40 hours at 08.00-12.00 am with a standard moisture content reaching 30-50% [4]. The development of drying methods with Seaweed Drying Dome resulted in a shorter drying period, moisture content of about 37%, cleaner, and whiter dried seaweed output, and less interference with rainy/cloudy weather that had the potential to grow bacteria. The design of the Seaweed Drying Dome installation can be seen in Figure 4 below.

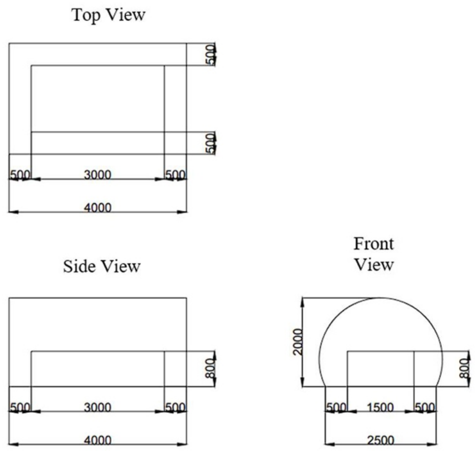

Fig. 4. Design of Seaweed Drying Dome

2.3 Station 3 – Carrageenan Processing Shop

At this stage, the design and installation of the carrageenan processing shop will be carried out through the estimation of production capacity, design of the processing stage, and layout of the workshop. A list of equipment for the carrageenan processing shop was procured and installed. The electricity supply is obtained by optimizing the potential output of renewable energy installation using solar PV. The trial of production was carried out at a temperature of 80 ºC for Alkali deposition and as a result, 50 grams of carrageenan flour were produced from 100 grams of dry seaweed. The carrageenan processing can be seen in Figure 5.

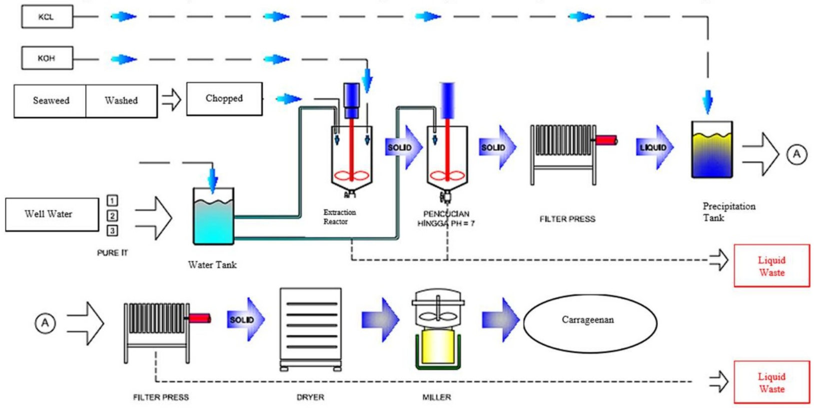

Fig. 5. Design of Carrageenan Processing Shop

2.4 Station 4 – The Renewable Energy Electricity Installation

The use of solar PV as a clean and renewable energy source was developed to supply the electricity of the carrageenan processing shop as well as the requirement of monitoring and control room. According to the Global Solar Atlas, Padike village, Poteran island, the installed capacity of solar PV is 2.34 kWP with tilt of PV panel 12 ºC. The solar PV installed on the roof of the carrageenan workshop. The layout of the carrageenan workshop can be seen in Figure 6.

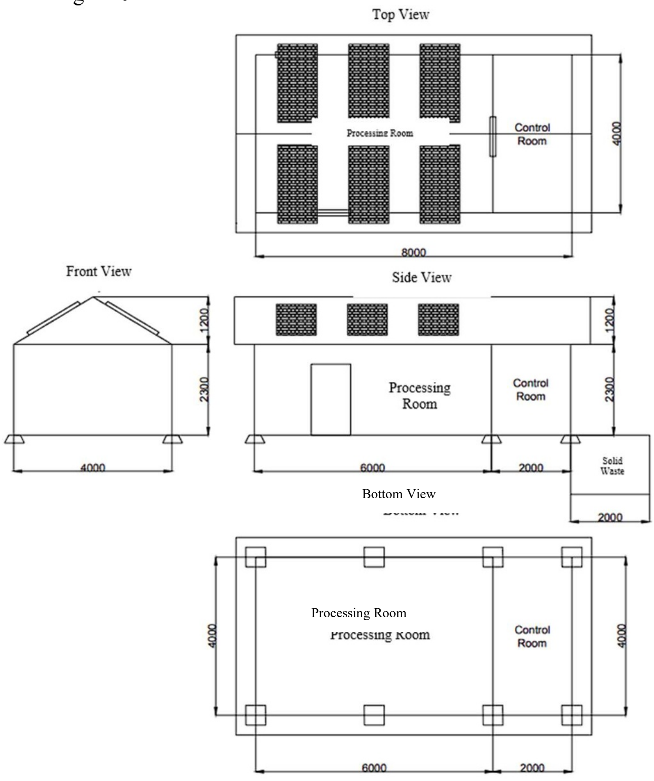

Fig. 6. Design of Electrical Installation Using Solar PV

2.5 Integrated Business Model

The 4 stations of the carrageenan production chain as discussed above, should be designed as an integrated business model. Each station has input requirement and based on its process, it produce certain number of output, as described in Figure 7. The specification of the integrated business model can be detailed as :

Station 4 – The solar PV electricity installation with an output capacity of 2.34 kWp/ 4 hours

Station 3 – The carrageenan processing shop, output of 5 kg/ 8 hours, price Rp. 245,000/ kg

Station 2 – The seaweed dry dome 2 kg dry seaweed / 5.5 hours, price Rp. 20,000/ kg

Station 1 – The cultivation farming 45 days/ period, the output of 75 kg wet seaweed/ floating cage and output price Rp. 2,000/ kg.

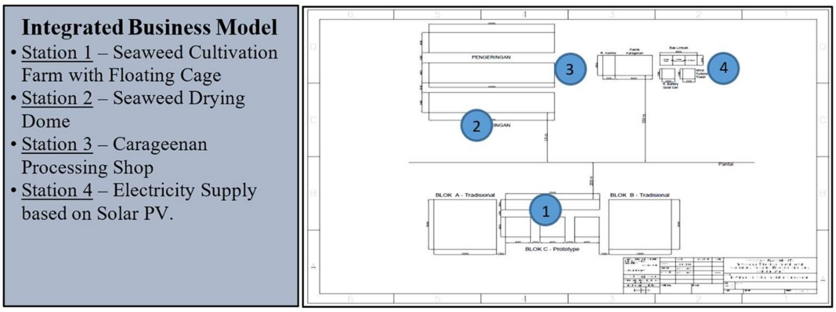

Fig. 7. Integrated Carrageenan Business Model

2.6 Linear Programming Method

A linear program is one of the mathematical models used to solve optimization problems, that is, maximizing or minimizing objective functions that depend on some input variables by taking into account various limitations (constraints) in resources. The mathematical model is prepared based on consideration of the (1) objective function that directs the analysis to the achievement of the objectives of the problem being analyzed, and the (2) constraint function that provides limits on the use of available resources and the demand for my resources. The optimization problem with linear programming is formulated as follows [5]:

$$max\ /\ min:$$
$$f = ax_1 + bx_2 + \ldots + nx_n \tag{1}$$

The objective function is subjected to the constraints function as described below:

$$subject\ to:$$
$$x_1 + x_2 \leq 1$$
$$x_1 + x_2 + x_n \leq 2$$
$$x_1, x_2, x_n \geq 0 \tag{2}$$

The linear programming function is formulated based on equations (1) and equations (2). Equation (1) serves as the objective function or goal to be achieved in the optimization problem. Optimization problems are generally formulated as either minimization or maximization functions. Minimization functions are typically used to minimize production costs, while maximization functions are employed to maximize revenue from a production process. The objective function is constrained by limitations primarily related to production capacities, as depicted in equation (2). In this particular optimization problem, the aim is to find the optimal values for each production station to achieve the optimal revenue from the process.

3 Result and Discussion

The proposed business model is an integrated business model consisting of four production stations that are interlinked in the carrageenan production chain. In the trial phase, the carrageenan production workshop yields an output of 5 kg every 8 hours. The set selling price for each kilogram is Rp.245,000,-, which follows the current market price trend for refined carrageenan products [6]. The main ingredient for producing carrageenan is dried seaweed. The seaweed cultivation period is 45 days, or approximately 1.5 months, with a target harvest of 3 tons or 3,000 kg. With this target, a total of 40 floating cages are needed, each with a capacity of 75 kg. In addition to developing carrageenan production, the integrated business model also includes independent electricity production using renewable energy systems such as solar panels. This self-produced electricity will also be distributed for the local community's electricity needs, with a tariff of Rp.605,- per kWh. This tariff aligns with the state-owned electricity company's rate for 900 kVA power usage, which is designated for subsidized household electricity consumption [7]. Table 1 below provides an overview of the processes to be optimized.

Table 1. Optimization Problem

Stations – Product	Product Output	Wet Seaweed – Input	Production time
1 - Wet Seaweed	3000 (kg) – **Rp. 2,000/ kg**	-	Per cycle in 45 days
2 - Dry Seaweed	2 (kg) – **Rp. 20,000/ kg**	2 kg /kg dry seaweed	Per 5.5 hours in 45 days
3 - Carrageenan	5 (kg) – **Rp. 245,000/ kg**	10 kg /kg carrageenan	Per 8 hours in 45 days
4 - Electricity Supply (kWh)	2.34 (kWP) = 2.34*0.8 (kWh) = 1.872 (kWh) – **Rp. 605/kWh**	-	Per 4 hours in 45 days

Based on the provided data, it can be observed that there are four variables whose production will be optimized. Each variable is represented by each production station. By utilizing the linear programming method, the optimization problem needs to formulate the objective function and also the constraints assumed as follows:

The production variables are formulated as follows:

x_1 = Wet Seaweed

x_2 = Dry Seaweed

x_3 = Carrageenan

x_4 = Electricity Supply

The next step is to formulate the objective function. In this case, each product variable will be optimized to generate maximum revenue. Based on this scenario, the objective function is formulated as follows:

$$Z = 2000x_1 + 20000x_2 + 245000x_3 + 605x_4 \tag{3}$$

Based on this objective function, it can be understood that the optimization function is to achieve maximum revenue from the products at each production station. The applicable constraint functions are as follows:

$$x_1 + 2x_2 + 10x_3 \leq 3000 \tag{4}$$

$$x_1 \leq 1080 \tag{5}$$

$$2x_2 \leq 65.45455 \quad (6)$$

$$5x_3 \leq 45 \quad (7)$$

$$2.34x_4 \leq 90 \quad (8)$$

$$x_1, x_2, x_3, x_4 \geq 0 \quad (9)$$

By using the linear programming method, the optimization results as shown in Table 2:

Table 2. Optimization Result Scenario 1

Variable	X1	X2	X3	X4
Product	Wet seaweed	Dry seaweed	Carrageenan	Electricity
Price	Rp 2,000 /kg	Rp 20,000 /kg	Rp 245,000 /kg	Rp 605 /kWh
Amount production	1080 Kg	32.72727 Kg	9 Kg	19.23077 kWh
Maximum profit in 45 days	Rp 5,031,180.07			

In Table 2, it can be observed that during one production cycle of 45 days, each production station must be able to produce 1080 kg of wet seaweed, 33 kg of dried seaweed, 9 kg of carrageenan products, and an electrical supply of 19.23077 kWh. These optimization results stem from the scenarios of each production station, generating marketable products and consequently affecting income.

Another scenario is applied to the carrageenan production business problem, where the resulting product is entirely carrageenan. If this scenario is implemented, out of the total 3000 kg of fresh seaweed products, 300 kg of carrageenan products can be obtained. This scenario is chosen as an alternative because of the relatively high market price for refined carrageenan powder. Considering the opportunities in the market and the independently conducted production process, including the electricity supplied from renewable energy sources, this scenario presents a rather appealing opportunity, as seen in the following Table 3.

Table 3. Optimization Result Scenario 2

Variable	X1	X2	X3	X4
Product	Wet seaweed	Dry seaweed	Carrageenan	Electricity
Price	Rp 2,000 /kg	Rp 20,000 /kg	Rp 245,000 /kg	Rp 605 /kWh
Amount production	0 Kg	0 Kg	300 Kg	0 kWh
Maximum profit in 45 days	Rp 73,500,000			

Tables 2 and 3 show the production optimization results for each product. In each table, the maximum profit value obtained in each production cycle for 45 days can be seen. This value is the value without any reduction in operational expenditure (OPEX) and capital expenditure (CAPEX), so that the CAPEX and OPEX values are ignored in both optimization results. To provide good optimization results, it is necessary to estimate CAPEX and OPEX calculations in its implementation. The CAPEX and OPEX calculations as well as the net profit value obtained during one 45 day production cycle are explained in Table 4 below.

Table 4. CAPEX and OPEX Calculation Estimation

	No	Item	Qty	Unit	Cost	Total Cost
CAPEX	1	Floating Cage	1	Set	Rp. 40,000,000	Rp. 40,000,000
	2	Production Workshop	1	Set	Rp. 110,000,000	Rp. 110,000,000
	3	Dry Dome	1	Set	Rp. 25,000,000	Rp. 25,000,000
	4	Solar PV Installation	1	Set	Rp. 85,000,000	Rp. 85,000,000
	5	Digital Monitoring Installation	1	set	Rp. 40,000,000	Rp. 40,000,000
Total CAPEX						Rp. 300,000,000
OPEX	1	Seaweed Seeds	600	Kg	Rp. 200	Rp. 120,000
	2	Workers	2	Man	Rp. 2,500,000	Rp. 5,000,000
	3	Manager	1	Man	Rp. 4,000,000	Rp. 4,000,000
Total OPEX / production cycle						Rp. 9,120,000

Table 4 shows the total costs that must be incurred in carrying out a carrageenan processing production business. The total CAPEX required to create integrated carrageenan processing production is estimated at Rp. 300,000,000 where the things included are the cost of making a floating cage, the cost of making a production workshop, the cost of making a drying dome, the cost of Solar PV installation, and the cost of digital monitoring installation. The total OPEX spent was Rp. 1,920,000 with cost components in the form of seaweed seeds, workers, and managers. The production scenario chosen is scenario 2 which is shown in Table 3 with a maximum profit value per production cycle of Rp. 73,500,000, then it is assumed that 50% of income is used to pay capital costs so that the total fixed expenditure for one production is Rp. 36,750,000. With that assumption, it is determined that capital costs will be paid off in the eighth production cycle. It is estimated that during one year there will be 5 times production so that in the second year, the amount of income received will be full.

4 Conclusion

An integrated business model based on linear programming could manage an interaction top-down stream of the seaweed production chain in a coastal community. The production chain starts with seaweed cultivation farming, seaweed drying dome, and carrageenan processing shop and is supported by clean and renewable energy. As a result, productive and optimum interaction among stations within the carrageenan production chain was achieved. In this issue, there are two scenarios applied. The first scenario involves optimizing all production stations, while the second scenario focuses solely on carrageenan production.

In the first scenario, it was found that by implementing product output in each station with its respective selling price, the maximum revenue obtained for 45 days is Rp. 5,031,180.07. When compared to the second scenario, where the business focus is on maximizing carrageenan production potential, the revenue obtained is significantly higher than in the first scenario. The prototype of the integrated business model of a carrageenan processing shop in Padike village on Poteran island is a practical example of a blue economy model that ensures the balance between economic growth, social equity, and a sustainable environment.

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