Cost Calculation for Commercializing Production of Microalgae Biofuels and Foundation Business Model: Case Study of Durban-city in South Africa

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Abstract

This study calculated production cost of outputs through microalgae cultivation, biofuel extraction, and residue utilization in wastewater treatment site of Durban-city, South Africa. To do so, it was summarized technological contents in each technology and to estimate these quantities and revenues from each product in scaling-up case. As results that minimum selling price of each output in largest scaling-up case are that microalgae biomass is ZAR 104.31/kg, microalgae biofuel is ZAR 1121.16/kg, and agri-mat is ZAR 19.56/mat. Furthermore, this study showed that some effect with producing in this project like energy saving or environmental conservation can contribute to realizing business model.

Keywords: microalgae biofuel, cultivation microalgae from wastewater treatment, cost calculation, business model, South Africa

1. Introduction

Biofuel are expected as substituted fuel of fossil fuels and carbon dioxide fixation to countermeasures of global climate change. However, utilization of biofuel is a problem that the estimated areas of cultivation for producing crop such as soybean and maize, which have traditionally been used in biofuel production is so huge. Instead of biofuel production from higher plants such as soybean and maize, that from microalgae is expected because of higher fixation capacities and smaller cultivation area than other plants.

Also, cultivation of microalgae has a merit that it is suited to the disposal of sewage including nutrients such as nitrogen and phosphorus. However, production of biofuel from microalgae is necessary to be a step for drying treatment, and this step is also necessary to consume a large energy. It is estimated that the required energies on biofuel production from microalgae are about twice or seventh times quantities compared than total calories of microalgae biofuels. Furthermore, there is also problem of residues disposal after biofuel extraction from microalgae.

This project "Production of Biofuels Using Algae Biomass in the Republic of South Africa" was supported by SATREPS (Science and Technology Research Partnership for Sustainable Development Program which funded by Japan Science and Technology Agency and Japan International Corporation Agency). The goals of this project are not only developing efficient technologies for cultivating microalgae from waste water treatment in Durban (Kingsburg Waste Water treatment in eThekwini Metropolitan Municipality, South Africa), extracting biofuel with DME (dimethyl ether), and fertilizer products with residues after extracting (agri-mat), but also creating business model with these technologies and developing capacity of human resources with utilizing these technologies (Handbook 1 of SATREPS Project, 2017).

The purpose of this paper is to introduce a business model which are utilized microalgae cultivation, biofuel extraction from microalgae, and producing fertilizer with residue of biofuel extraction. To do so, it is shown to calculate production cost of these outputs and to estimate these quantities and revenues.

The contents of this paper are as follows; section 2 introduces overviews of each technological outcomes on cultivation microalgae from wastewater treatment, biofuel extraction with DME from cultivated microalgae, and agri-mat production from residues of extracted microalgae and the utilization to agricultural production; section 3 shows scale-up case based on the outcomes in this project. This chapter summarizes current scales in each technology, and then two cases is set; first is expansion to the whole Kingsburg wastewater treatment (WWT), and second is expansion to all WWT in Durban; section 4 shows the results of calculations on producing cost and output in each scaling-up case. And I show to creating business model on fuel substitution from diesel to biofuel on vehicles for water treatment owned by eThekwini; and section 5 remarks conclusion in this paper.

2. Technological Overview of Cultivation Microalgae in WWT, Biofuel Production of DME Extraction, and Utilization of Residue by Agri-mat Production

2.1. Overview in SATREPS Project

The objectives of this SATREPS project are, firstly, to contribute to CO2 emission reduction through cultivating microalgae from wastewater, producing biofuels from microalgae with DME extraction and developing a new fertilizer in the form of an "agri-mat" via hot pressing, which consists of microalgae residue and wood chips.

The technological features of our SATREPS project are (1) cultivating microalgae with raceway pond in WWT, (2) extracting biofuel with DME, (3) producing agri-mat mixed residues after extraction.

Firstly, WWT management is spent to public finance by public sector such as governments but does not make an economic profit. Cultivating microalgae with wastewater of WWT and its commercializing imply that WWT can make an economic profit and reduce the burdens by governmental sector. Moreover, microalgae have the high photosynthetic ability, and so it has high and efficient fixation effect of CO2 emission.

Furthermore, it is expected that cultivation microalgae can utilize the origin of the biofuel, and substitute to fossil fuels such as oil. However, for algae fuel production, the process of drying harvested microalgae and the recycling of nitrogen and phosphorus are very important. Generally, water content of microalgae is over 80% even after microalgae is harvested by centrifuge or agglomeration dewatering. Due to this high moisture condition, lipids cannot be extracted by a typical nonpolar solvent such as hexane which is not mixed with water. Therefore, drying is effective as a pre-treatment to increase the lipid amount extracted from microalgae, but is highly energy intensive.

Secondly, to solve these problems, with utilizing DME on the step of extraction biofuel, it can omit the drying step is required. Direct extraction of lipids from wet harvested microalgae is effective in the reduction of energy consumption in algae fuel production. This SATREPS project developed the scaled-up equipment for extracting biofuel with DME in Kingsburg WWT. This technology can provide the effective energy saving effect and utilize to substituted fuel of fossil one.

Microalgae cultivation using wastewater is found to be very effective in the recycling of nitrogen and phosphorus, the nitrogen content in microalgae is higher than in other plants. After lipid extraction from microalgae, a nitrogen-rich residue remains. Therefore, thirdly, residue can be used as fodder for stockbreeding or fertilizer for agriculture. This SATREPS project make steps to develop a new fertilizer in the form of an "agri-mat" via hot pressing, which consists of microalgae residue and wood chips. Nitrogen components of microalgae residue will seep from the agri-mat to the soil after undergoing a process which converts it to a carpet-like form made with wood chips. This technology can provide the effects of increasing and high-valued agri-production, prevention of soil erosion or water saving.

The main contents in this SATREPS project are as above. Each technology has both the effective environmental conservation effects and high economic profits. Otherwise, these contents can involve some by-products. For example, cultivated microalgae can utilize to feed for culturing fish or animal. To sell these cultured fish or animal meat can make economic profit. Furthermore, microalgae are used to produce some high value products such as cosmetic goods, supplements, or health foods. The scale of these market is predicted to increase it and enhance the added values.

Figure 1 shows a flow diagram in the project.

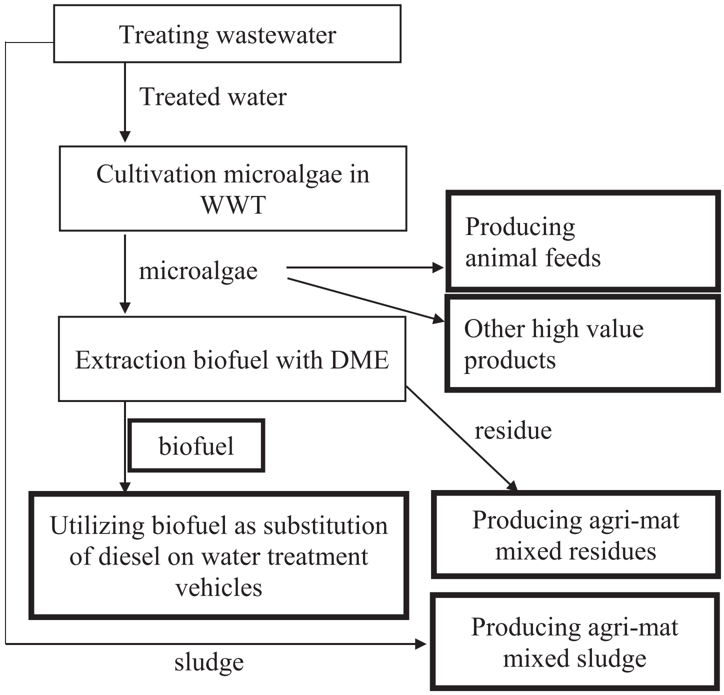

Figure 1 Flow diagram in this SATREPS project

(source) Author's creation.

2.2. Outcomes of Technological Development in this Project

The aim of the project is to produce a technology package for the production of biofuels from algae using wastewater by nutrient and water source thereby providing tertiary treatment which could assist wastewater treatment plants in meeting discharge standards. Developed culture was then transferred to 3000L ponds at Kingsburg site for outdoor cultivation and scale up. Algal cultures were first acclimatized to outdoor conditions in standard growth medium and then grown in wastewater for further development of seed culture. Finally, it was scaled up 300,000L open raceway pond in Kingsburg WWT. Tab. 1 explains capacity of open raceway pond in Kingsburg WWT.

The utilization of biofuel with microalgae contributes to CO2 reduction with substitution of fossil fuel. However, there is a problem which must consume a larger energy to produce biofuel from microalgae because this production needs to be a dried process. To solve this problem, DME has a role to save this dried process by extracting with DME from wet

Tab. 1 Capacity of cultivation pond in Kingsburg WWT

Type	Raceway
Capacity	300 ton
Area	1146m^2
Depth	30cm
Growth speed	1620 ppm in 14–17 days
Velocity of current	8–11 meter/min
Cultivated species	Scenedesmus sp. and Chlorella sp.
Built by	eThekwini Municipality
Year	2010
Main features	Mass cultivation of algae using treated sewage water as fertilizer 72% reduction of nitrogen fertilizer consumption with utilizing secondary treatment effluent on WWT

(source) Author's creation based on research outcomes by Nagoya U. (2022) "Final Outcome Documents of SATREPS project".

microalgae directly. Moreover, the residue of microalgae after extraction can use as fertilizer for existing a large nutrient such as nitrogen and phosphorus by using DME which omits to drying process of microalgae.

This SATREPS project developed DME extraction equipment and installed at Kingsburg WWT in 2019. The size of this extraction tank is 30L, which is maximum size as large as possible in the budget of this project. In field test, to achieve more effective extraction with DME, we attempted to extract it by mixing with microalgae and sugar-cane bagasse because DME makes it easier flow to the whole microalgae. As the result, by DME extraction with mixing microalgae of 11.1kg and bagasse of 5.5kg (in each wet wt), it succeeded to extract lipid oil of 93.2% and water of 99.0%. Furthermore, the residue was dry, and can be used to process the agri-mat as fertilizer. Currently it is progressing to be examined more efficient and effective extraction ways such as mixing cellulose ball to microalgae. Process of mixed microalgae lipid can be extracted by mixing microalgae of 20kgwet and cellose ball of 2.2kg. And, in Kingsburg WWT, these microalgae are harvested by cetrifuge-type harvester which was produced and transferred from Japan.

Agri-mats can have both economic and environmental benefits when used as a protective layer in small-scale farming systems. Because of their ability to retain soil moisture and fertile topsoil, agri-mats can increase agricultural production especially in areas with low annual rainfall. Another way the mats can save farming costs is their weed suppression abilities, which eliminates the cost of weeding and the need to apply weedicides. By retaining soil moisture, the irrigation frequency and hence irrigation cost is also significantly reduced. The environmental benefits of using agri-mats which are not so easy to quantify in monetary terms, include the regulation of soil temperature, improvement of soil structure, promotion of soil microbial activities, soil fertility improvements and thus enhancement of vegetation or crop productivity especially in semiarid regions.

This project developed some type machine of agri-mat, firstly, small-size machine on desk, and continueslly hot press machine and cold one. The contents of hot press machine is shown to Tab. 2.

Tab. 2 Contents of hot press machine for producing agri-mat

Item	Specification
Heating plate size	450×450mm
pressing force	80–294kN (8 ～ 30ton)
heating temperature	RT－300℃
power supply	3phase, AC200V, 40A
cooling system	air cooling, water cooling (150℃ or less)
Weight	715kg

(source) Author's creation based on research outcomes by Nagoya U. (2022) "Final Outcome Documents of SATREPS project"

The size of ordinal agri-mat is 50 (cm) *25 (cm)* 1–1.5 (cm), and the compositions to produce a board agri-mat are sugarcane bagasse of 480g, residue of 24g, and MgO (magnesium oxide) powder of 24g which is used as main binder. Instead of the bagasse, sludge which are emitted from wastewater treatment can be used.

3. Setting to Scaling-up Case

3.1. Real Output in this project

As mentioned in ch. 2, I summarized technical features and present situations of each technology, cultivation microalgae in raceway pond with sewage, extraction biofuel with DME solvents, and production agri-mat with mixing residue after extraction. And I also showed flow diagram which explained relationship between each technology and some output. This chapter shows current output based on these figures of each technological experiments.

First, on cultivating microalgae in raceway pond with sewage, quantities of cultivated microalgae output are about 1620ppm during 14–17 days in this project. As the pond size is about 300,000L, weight quantities (Q_a, unit: kg) during this period can estimate in below equation (1);

$$Q_a = 300{,}000\ (\mathrm{L}) \times 1620\ (\mathrm{ppm})/1{,}000{,}000 \fallingdotseq 486\ (\text{kg-wet}). \qquad \cdots\cdots\cdots(1)$$

In this weight of harvested microalgae, water is contented less than 91%, and weight of pure microalgae is estimated at about 43.7kg.

Secondly, on DME extraction equipment, quantities of wet-microalgae which can extract per time are 20kg-wet with cellose ball of 2.2kg. This study assumes that these microalgae are contained water by 91%, and microalgae except water are contained lipid by 29.6%. This DME extraction can extract lipid of 93.2% in algae, so that the estimated weight of lipid per time (Q_{el}) can be calculated in below equation (2);

$$Q_{el} = 20\ (\mathrm{kg}) \times (1 - 0.91) \times 0.296 \times 0.932 \fallingdotseq 0.497\ (\mathrm{kg}). \qquad \cdots\cdots\cdots(2)$$

From this calculation, weight of residue after extraction lipid from microalgae is estimated at about 1.303kg. And as microalgae for extracting lipid is used by 20kg per a time, cultivating it during 14−17days can use on 24 times. Assumed hours for extracting it with DME is on about 3 hours, as it could be extracted on 2 times per day, this quantities of cultivated microalgae per a time can use for 12 days. And quantities of lipid from microalgae on harvesting per a time, that is for 14−17 days is estimated at about 11.9kg.

Thirdly, as it is necessary to use residue of 24g for producing a board of agri-mat, we can produce about 54 boards from quantities of cultivated microalgae per time. These boards can set to cultivate field area of about 6.75m^2.

Based on the above figures on each process, Tab. 3 is summarized to each output per year in case cultivation microalgae can work in 350 days per year. This situation of working days in a year is optimal case which keep a minimum day to maintain to pond.

Tab. 3 Output of each technology in baseline and a year

	unit	baseline per time	baseline per year
cultivation microalgae	t	0.486	9.72
extracting lipid from microalgae	kg	0.497	241.33
residues after extracting microalgae	kg	1.303	633.47
quantities of agri-mat production	boards	54	26,394

(Note) Working days of cultivating microalgae at raceway pond in WWT assume 350 days in a year and harvesting times per year is 20 times.
(sources) Calculated results by author based on Nagoya U. (2022) "Final Outcome Documents of SATREPS project".

To establish business model and commercialize it with each technology, it is necessary to expand the scale to obtain economies of scales with lower average cost to produce them.

Based on this result of Tab. 3, this study set to two scaling up cases; first case is to expand to whole Kingsburg WWT; and second case is to expand to all wastewater treatment in Durban city.

3.2. Expansion to whole Kingsburg WWT

First case is to expand to whole Kingsburg WWT. The disposal quantities of sewage in whole Kingsburg WWT are about 6 million L (Moodliar, 2014). Thus, this assumes that the scale of cultivating microalgae in the whole Kingsburg WWT expand about 20 times compared to baseline scale. Otherwise, this study assumes that technology level to its cultivation is not change (i.e. quantities of cultivated microalgae output is about 1620ppm during 14–17 days). Of course, it may change to producing more efficiently with innovating it but the calculations in this time assume a stable level of each technology.

Firstly, on the whole Kingsburg WWT with about 6 million L, weight quantities ($Q_{a\text{–}6M}$, unit: kg) during the period of 14–17days are about 9720kg-wet, and this algae except water consists of 874.8kg. We calculate that extracted lipid from this microalgae ($Q_{el\text{–}6M}$) are about 241.33kg, and the residues are 633.47kg. Thus, agri-mat of 26,394 board are produced.

Based on these results, Tab. 4 is summarized to each output per year. As a result, by producing during a year, output of microalgae is 194.4t, that of the lipid is 4.83, that of residues is 12.67t, and that of agri-mat is 527,916 boards.

Tab. 4 Output of each technology in scaling-up to 6ML WWT

	unit	baseline per time	baseline per year
cultivation microalgae	t	9.720	194.40
extracting lipid from microalgae	t	0.241	4.83
residues after extracting microalgae	t	0.634	12.67
quantities of agri-mat production	boards	26,394	527,916

(Note) Working days of cultivating microalgae at raceway pond in WWT assume 350 days in a year and harvesting times per year is 20 times.

(sources) Calculated results by author based on Nagoya U. (2022) "Final Outcome Documents of SATREPS project".

3.3. Expansion to all WWT in Durban

Second case is to expand to all WWT in Durban city. The disposal quantities of sewage in all WWT of Durban city are about 500 million L (Moodliar, 2014). And there are 27 wastewater treatments in eThekwini Municipality. Thus, this study assumes that the scale of cultivating microalgae in the whole Kingsburg WWT expand about 1666 times compared to baseline scale.

Firstly, on the whole Kingsburg WWT with about 500 million L, weight quantities (Q_{a-500M}, unit: kg) during the period of 14–17days are about 810 t-wet, and this algae except water consists of 72.9t. This study calculates that extracted lipid from this microalgae ($Q_{el-500M}$) are about 20.11t, and the residues are about 52.79t. Thus, agri-mat of 2,199,539 board are produced.

Based on these results, Tab. 5 is summarized to each output per year. As a result, by producing during a year, output of microalgae is 194.4t, that of the lipid is 4.83, that of residues is 12.67t, and that of agri-mat is 527,916 boards.

Tab. 5 Output of each technology in scaling-up to 500ML WWT

	unit	baseline per time	baseline per year
cultivation microalgae	t	810	16,200
extracting lipid from microalgae	t	20.11	402
residues after extracting microalgae	t	52.79	1,056
quantities of agri-mat production	boards	2,199,539	43,990,776

(Note) Working days of cultivating microalgae at raceway pond in WWT assume 350 days in a year and harvesting times per year is 20 times.
(sources) Calculated results by author based on Nagoya U. (2022) "Final Outcome Documents of SATREPS project".

4. Calculations of Cost on each Scaling-up Case

4.1. Initial Cost in each Equipment

As it is summarized in ch. 3, each output of baseline in this project depends on the scale of pond in WWT. In this chapter, I explain some cost in each scaling-up. The cost consists of initial cost which are set in starting time of production such as raceway pond, harvesting machine, extraction equipment with DME solvent, and press machine for producing agri-mat, and operation cost which need to implement their productions such as some materials, electricity, and labors. In this section, I firstly explain the initial cost in baseline, and calculate them in each scaling-up case.

Firstly, I estimate initial cost of open raceway pond in Kingsburg WWT. According to report of Davis, et.,al., (2016), total initial cost that the surface of pond is about 4ha (40,000m^2) is estimated on \$390.2 million. The surface of the raceway pond in Kingsburg WWT is 1146m^2, and the scale of pond is 17626.6 times larger than that of Kingsburg WWT. This study calculates the initial cost ($C_{init\text{-}base}$) of open raceway pond in Kingsburg WWT. On calculating it, 0.6 rule based on the economies of scale was adopted. And the equation of the calculation is as follows (3);

$$C_{init\text{-}base} \times 17626.5^{0.6} = 3090{,}200{,}000 \text{ (USD)} \qquad \cdots\cdots\cdots(3)$$
$$C_{init\text{-}base} = 1{,}105{,}572 \text{ (USD)}$$

Exchange rate between US dollar (USD) and Rand of South Africa (ZAR) is assumed by fixing as USD 1 = ZAR 15, and $C_{init\text{-}base}$ of ZAR unit is calculated as ZAR 16,583,587. It was calculated as expanding to each scale to 20 times and to 1666 times and was showed in Tab. 6 on the cost to each scale. In this calculation, this study used 0.6 rule to expansion to the scale.

Tab. 6 Calculation Results on Initial Cost of Open Raceway Pond in each Scale

	Initial Cost of ORP (unit: ZAR)	Scale of Pond (unit: L)
Baseline scale	16,583,587	300,000
Whole Kingsburg WWT	100,068,288	6,000,000
All Durban WWT	1,421,292,523	500,000,000

(sources) Calculated results by author based on Nagoya U. (2022) “Final Outcome Documents of SATREPS project”.

Secondly, on harvesting machine, the machine in Kingsburg WWT is cetrifuge-type harvester, which are possible to harvest microalgae of 7t per hour in maximum capacity. The cost of this machine including main machine and incidental facilities like control panel, pump, bulb, and cost of installing works is JPY 29,500,000 (ZAR 3,687,500, this was calculated by exchange rate as ZAR 1 = JPY 8, referred to the quotation document of this machine in 2018). This study calculated the cost in each scaling-up case with 0.6 rule. These results were summarized in Tab. 7.

Tab. 7 Calculation Results on Initial Cost of Harvesting Machine in each Scale

	Initial Cost of Harvesting Machine (unit: ZAR)	Note
Baseline scale	3,687,500	Harvesting capacity is 7t/hr.
Whole Kingsburg WWT	22,251,025	Expanding to 20 times compared with baseline.
All Durban WWT	316,036,343	Expanding to 1666 times compared with baseline.

(sources) Calculated results by author based on Nagoya U. (2022) “Final Outcome Documents of SATREPS project”.

Thirdly, on DME extraction equipment, this project was developed the scaling-up size tank which can extract large number of microalgae by 30kg-wet. The quotation document of initial cost on the DME extraction equipment are included the cost for developing this equipment or for testing it, and so this cost consists of the equipment and the incidental facilities like control panel, pump, bulb, and their installing works only, as the result the cost is JPY 24,170,000 (ZAR 3,021,250, this was calculated by exchange rate as ZAR 1 = JPY 8). This study calculated the cost in each scaling-up case with 0.6 rule. These results were summarized in Tab. 8.

Tab. 8 Calculation Results on Initial Cost of DME Extraction Equipment in each Scale

	Initial Cost of Extraction Equipment (unit: ZAR)	Note
Baseline scale	3,021,250	
Whole Kingsburg WWT	18,230,755	Expanding to 20 times compared with baseline.
All Durban WWT	258,935,539	Expanding to 1666 times compared with baseline.

(sources) Calculated results by author based on Nagoya U. (2022) "Final Outcome Documents of SATREPS project".

Finally, on agri-mat press machine, similarly DME extraction equipment, this machine is developed and produced on hot press and cold press one. The initial cost of agri-mat press machine is hot press type one because this type is general technology than cold press one. The initial cost of hot press machine is JPY 4,971,240 (ZAR 621,405, this was calculated by exchange rate as ZAR 1 = JPY 8). This study calculated the cost in each scaling-up case with 0.6 rule. These results were summarized in Tab. 9.

Tab. 9 Calculation Results on Initial Cost of hot press machine of agri-mat in each Scale

	Initial Cost of hot press machine of agri-mat (unit: ZAR)	Note
Baseline scale	621,405	
Whole Kingsburg WWT	3,749,667	Expanding to 20 times compared with baseline.
All Durban WWT	53,257,373	Expanding to 1666 times compared with baseline.

(sources) Calculated results by author based on Nagoya U. (2022) "Final Outcome Documents of SATREPS project".

4.2. Operation Cost in each Production Process

This section is explained the operation cost in each technology. Main material cost of each operation is included on nitrate and phosphate for cultivating microalgae, cellose ball for extracting with DME, or ahesive like MgO for producing agri-mat. And operation cost includes cost of electricity consumption or labor to their production. It is summarized as main operation cost in each production in Tab. 10.

Tab. 10 Main price for using in each operation

	price	unit	Note
nitrate	17.80	ZAR/kg	quantities of usage: 250mg/L
phosphate	45.76	ZAR/kg	quantities of usage: 40mg/L
electricity	1.61	ZAR/kWh	Based on ESKOM (power utility) rates in Feb. 2022.
cellose ball	7.50	ZAR/kg	quantities of usage: cellose ball of 2kg for extracting microalgae of 20kg
ahesive for producing agri-mat (MgO)	200.000	ZAR/kg	quantities of usage: 0.084kg/mat
wage to labor	23.19	ZAR/hr	Based on current minimum wages by Dept of Labor.

(sources) Calculated results by author based on Nagoya U. (2022) “Final Outcome Documents of SATREPS project”.

In addition, electricity consumption for production of lipid from microalgae was estimated and was shown that electricity consumption for harvesting microalgae from ORP is 20.1, whereas that for extracting lipid is 2.28 compared with that for producing energy including microalgae in cultivation water is 100.

4.3. Calculations of Minimum Selling Price in each Scale

This section shows the results of minimum selling price (MSP) in each scale of microalgae production. MSP is the average cost which is obtained by divided the total cost by total quantities of production, and this price level means that the profit is zero during a period on a scale of production. In other words, this means that the price more than MSP can provide a profit to us. Tab. 11 shows the results of calculations on MSP in each output; MSP of lipid from microalgae with DME extraction is ZAR 1516.83/kg, and that of microalgae biomass from WWT is ZAR 170.27/kg, and that of agri-mat with mixing residues after extracting biofuel is ZAR 29.48/mat.

Next, this study estimates MSP in each scaling-up case; case of expansion to the whole Kingsburg WWT (increasing the scale of pond by about 20 times), and one of expansion to all WWT in Durban (increasing the scale of pond by about 1666 times). I show the results of estimation of MSP based on the output estimation in ch. 3 and some cost estimation in this chapter on Tab. 12. As the results, MSP of microalgae biomass decreased by about 30%, that of lipid from microalgae decreased by about 20%, and that of agri-mat decreased by about 17% compared than that of baseline case.

Tab. 11 Minimum Selling Price of each Output on Baseline

output	MSP	Unit
Microalgae biomass	170.27	ZAR/kg
Lipid from microalgae	1516.83	ZAR/kg
Agri-mat	29.48	ZAR/mat

(Note) Working years of each machine are assumed to 30 years. Working days of cultivating microalgae at raceway pond in WWT assume 350 days in a year and harvesting times per year is 20 times.
(sources) Calculated results by author based on Nagoya U. (2022) "Final Outcome Documents of SATREPS project".

Tab. 12 Minimum Selling Price of each Output on scaling-up to the whole Kingsburg WWT

output	MSP	unit
Microalgae biomass	120.73	ZAR/kg
Lipid from microalgae	1224.58	ZAR/kg
Agri-mat	24.64	ZAR/mat

(Note) Working years of each machine are assumed to 30 year. Working days of cultivating microalgae at raceway pond in WWT assume 350 days in a year and harvesting times per year is 20 times.
(sources) Calculated results by author based on Nagoya U. (2022) "Final Outcome Documents of SATREPS project".

Tab. 13 Minimum Selling Price of each Output on scaling-up to all WWT in Durban

output	MSP	unit
Microalgae biomass	104.31	ZAR/kg
Lipid from microalgae	1121.16	ZAR/kg
Agri-mat	19.56	ZAR/mat

(Note) Working years of each machine are assumed to 30 year. Working days of cultivating microalgae at raceway pond in WWT assume 350 days in a year and harvesting times per year is 20 times.
(sources) Calculated results by author based on Nagoya U. (2022) "Final Outcome Documents of SATREPS project".

And Tab. 13 shows the results of MSP estimation on scaling-up to all WWT in Durban, and MSP of microalgae biomass decreased by about 39%, that of lipid from microalgae decreased by about 27%, and that of agri-mat decreased by about 34% compared than that of baseline case.

These results of MSP imply that scaling-up in each production can provide economies of scale thorough a lower unit production cost. Moreover, on estimation in this time, we didn't consider technological progress. And so that implies it has capacity each technology can be lower MSP and have a competitiveness in the market.

4.4. Creation Business Model

Main output in this project is lipid from microalgae with DME extraction. This can use as substitutional fuel of diesel vehicles owned by WWT of eThekwini municipality. Now there are about 3,300 diesel vehicles in WWT of eThekwini municipality, and it is possible to reduce emission of greenhouse gases by substituting them to biofuel which is refined by lipid extracting from microalgae biomass. However, the price of this biofuel from lipid extraction with DME is so higher than that of existing fossil fuels or other biofuels as competitors, and thus higher price of these biofuel from microalgae lipid may have disadvantage to lower price goods of other fuels. On the other hand, fuel substitutions of diesel vehicles owned by WWT of eThekwini municipality can provide some profits.

First profit is by saving costs. Especially, actual fuels of WWT's diesel vehicles are procured oil products like light oil from outside suppliers. By supplying biofuel by themselves from cultivating microalgae in WWT, they can save the cost for procurement of fuels like light oil through using microalgae biofuel. This can also provide for decreasing the cost burdens by public finance in the municipality.

Second profit is by reducing CO2 emission and by making economic profit. Substitutions of fuels from fossil fuels to biofuels can provide reduction of a direct emission by using light oil. This can make an opportunity to obtain a carbon credit by decreasing CO2 emission from WWT's vehicles. Obtaining carbon credit can obtain not only economic profits to do it but also environmental benefit and social values.

Third profit is possible to obtain by avoiding the market competition. As it is mentioned above, the competitiveness of this microalgae biofuel in the market, even if the scale of production is expanded, is not high because of the higher price. Utilizing the microalgae biofuels as substitutional fuels of the diesel vehicles owned by WWT in eThekwini municipality can avoid to market competitions between other fuels and acquire the stable demand by public sector.

Furthermore, producing and selling agri-mat with utilizing residues after extraction microalgae have effects not only saving the disposal cost of residue but also covering up the market disadvantage of the biofuels. As mentioned above it, agri-mat has price competitiveness in the market compared with the biofuels. In addition, the by-product benefits of agri-mat are effective and efficient environmental conservation effects like saving water supply to crop fields or preventing to soil erosion.

5. Conclusions Remarks

This study calculated cost and revenues from microalgae cultivations, biofuel with DME extraction, and residue utilization by producing agri-mat and suggested a business model based on these calculations. Conclusions of this paper are as follows; firstly, this study was summarized some features of each technology (microalgae cultivation on WWT, microalgae biofuel with DME extraction, agri-mat production with residue after extraction) and output in real level; secondly, this study calculated some cost to produce above output in real level and estimated them in scaling-up case. Results of these estimations means whether selling prices of these outputs are competitive or not. As results that minimum selling price of each output in largest scaling-up case are that microalgae biomass is ZAR 104.31/kg, microalgae biofuel is ZAR 1121.16/kg, and agri-mat is ZAR 19.56/mat; thirdly, based on the results of cost calculations, each output quantities estimation and introducing minimum selling price, this study created business model in this project. For establishing sustainable business model, this study showed that it is not enough to depend on selling microalgae biomass and the biofuel only but is necessary to sell agri-mat with residue after extraction and other products such as high value products from microalgae biomass. Furthermore, this study also showed that some effect with producing in this project like energy saving or environmental conservation can contribute to realizing business model. As the results, this study showed that a various revenue from output of some products can make profits through business through microalgae cultivation, biofuel extraction, and residue utilization with agri-mat production.

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