IJECBE (2024), **2**, **1**, 61–78
Received (18 January 2024) / Revised (18 January 2024)
Accepted (2 February 2024) / Published (30 March 2024)
https://doi.org/10.62146/ijecbe.v2i1.33
https://ijecbe.ui.ac.id
ISSN 3026-5258

International Journal of Electrical, Computer and Biomedical Engineering

RESEARCH ARTICLE

Dynamic Model on Palm Oil Production Capacity Using Variable CPO Stock for Biofuel Production

Arrie Tjahyo Setiawan and Rinaldy Dalimi*

Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia, Depok, Indonesia
*Corresponding author. Email: rinaldy@eng.ui.ac.id

Abstract

As the world gradually moves toward the net zero emissions target, renewable energy is believed to be one alternative widely adopted. The role of biofuel for running diesel power plants is therefore indispensable for compensating various renewable plants with fluctuating output, maintaining stability to the overall power system. For expanding biofuel production, keeping the rate of investment in CPO mills is critical, as it is often driven by CPO business profit. The seasonal nature of palm-oil plantation harvest directly influences CPO production behaviour. This research investigates system dynamics model simulation for CPO production system, indicated by the feedback loop from market demand, hence influencing the daily (or monthly) CPO production to provide revenue stream to the business. Subsequently, it influences the rate of investment for increasing production capacity, forming the dynamic hypothesis for the system. The model was developed using more endogenous variables (feedback in a close-loop, improvement to other system dynamic simulations often being modeled as open-loop), while trying to reduce the number of external inputs required to run the simulation. By substituting the price variable with the level of CPO stock at the national level, less uncertainties would affect the system such as price instability situation. Feedback signal from the level of CPO stock was utilized to control the simulated amount of CPO production, as well as the rate of re-investment for expanding the country's production capacity. Model simulation results were able to reproduce the system behaviour for capacity increase, to meet CPO market demand, using reduced number of variables for representing a few data input with limited availability. The model structure could be further replicated for efficiently developing the dynamic model for basic commodity production, where the rate of commodity production would not influence the overall market demand (decoupling of production rate from global market).

Keywords: CPO production, market demand, stock and flow, system dynamics, capacity, investment,

current asset

1. Introduction

As a vegetable oil extracted from palm-oil FFB (fresh fruit bunch), CPO (crude palm oil) is consumed by various downstream product refineries/factories. Typical mill's ratio of CPO/FFB amount is commonly valued at 0.20-0.22, for nearly all CPO extraction technologies. Downstream process of CPO's natural fatty-acids in vegetable oil refineries yield a range of downstream consumer products such as biofuel, cooking oil, and various food or chemical feedstock materials. With such a wide-range of CPO buyers, and producer entities (CPO mills), the Indonesian Bureau of Statistics and industry associations may keep track of the tonnes of CPO consumptions and production amount.

Palm oil FFB is one of the major agricultural commodities, with production database maintained by relevant Government Agencies. Hence, the amount of FFB purchased (indicating the amount of CPO produced on certain months) often does not equal to CPO sold to buyers. Such difference of values between CPO produced and sold is regarded as the monthly 'change in stock', where its level may fluctuate between 1 – 7 million tonnes of CPO in some extreme cases. Typical value of such stock quantity is in the range of 3.5 – 4 million tonnes, for the Indonesian case. Therefore, periodic changes in CPO-order demand (amount of CPO sold) would not immediately be transmitted to the changes in CPO-produced, where the CPO-stock serves as some kind of buffer amount.

2. Issues identification

Early development of system dynamics modelling addressed industrial supply chain problems, with separate submodel for business profitability and another submodel for capacity planning [1]. Later on, each industry sector would try to model their own integrated simulation, such as Lertpattarapong on IT product manufacturing [2], and Morecroft on oil & gas exploration/production [3]. However, its applicability was not directly clear on a primary commodity with persistent market demand, such as food/bulk-materials), as it implies a closed loop model on the overall process (behaviour at a larger scale), not just for the local loop (behaviour that is limited to small scale). Other research activities on the energy system, biofuel or CPO production were mainly simulating open loop model at a larger scale [4] [5], hence did not take into account dynamic behaviour focusing on the production facilities, where data is often scarce due to its nature of commercial business operations.

Current research identifies feedback loop mechanism in the CPO production system dynamics simulation, with a close-loop model simulation at production facilities scale, as an improvement to other system dynamic simulations often being modeled as open-loop), while trying to reduce the number of external inputs required to run the simulation. Taking one example of substituting the price variable with the level of CPO stock at the national level, less uncertainties would affect the system such as price instability situation. Addressing the gap in previous studies, results of this research would serve as a basic module for subsequent expansion of the production system dynamics model, with replicability options. This option is important, to enable model simulation where commercial data is limited, while trying to identify proxy variables to produce the intended system behaviour for representing components (submodel) in the overall simulation.

Previously, overview on CPO product value chain was indicated by Yaacob [6] through Porter's 5 forces, taking an example for Malaysian market, being relevant to Indonesia as well. It covered the business-sector internal competition (BIC), new-entrants threat (NET), product-substitute threat (PST), suppliers' bargaining-power (SBP) and buyers' bargaining-power (BBP).Taking example of applying these approach to the CPO industry (at two distinct systems), the first system analysis covers the CPO mill company (as a corporate analysis, looking at a single business entity against other CPO business entity in the similar market), while the second system analysis is on the CPO market (as a sectoral analysis, looking at all CPO business entities against overall vegetable oil/compatible products on a larger market).

This research focuses on production-capacity growth and supply-demand dynamics at the national level, so that for understanding the CPO processing industry behaviour, the second system on CPO market (as a sectoral analysis) is considered quite relevant. Yaacob then indicated that the second system has the force of BIC quite high, NET is low, PST is medium, SBP is low and BBP is high. One observation was that when analyzed from the market perspective (second system), it might indicate that CPO trading is often on a 'buyer-market' type. Such market (in a developing country, where population growth is considerably higher than in developed country) tend to sustain commodity production growth in a long period, e.g. 30 years or more, to meet demand following the nation's economic growth as well.However, from the company perspective, such a buyer-market situation might put them in a less favourable position. Due to such weak market power of the CPO industry, the dynamic model intentionally decouples the market demand volume from CPO mill production amount.

A stock variable is used for partial-decoupling of the demand signal, before influencing the system for CPO production. This stock (or 'level' variable) has the capacity for temporarily store, and accumulate, the produced CPO to meet market demand, hence absorbing the seasonal cycle, to some extent, in the simulated FFB harvest amount (high/low season on every few months of the year). Such a seasonal CPO production behaviour was represented by the Indonesian Palm Oil Association, IPOA (or Gabungan Pengusaha Kelapa Sawit Indonesia, GAPKI) industry association statistics, described in Fig.1 below. Subsequently, the level of CPO stock influences the system behaviour, being one of the input feedbacks to the rate of capital re-investment, as well as feedback to other variables.

This modeling approach aims at developing a typical structure for bulk commodity market such as CPO and similar agriculture processing facility. Productivity of CPO mills is related to the level of re-investment for expanding CPO production capacity. The amount of CPO product (from a large number of CPO producers) is consumed by an even larger number of buyers, both domestic and overseas.

CPO industry structure is often characterised by: (i) hundreds of CPO mill companies (small, medium, large scale) presenting nearly perfect competition; (ii) medium/high barrier-to-entry for CPO mill investment; and (iii) very little to zero differentiation of product qualities among virtually identical products. Such industry structure typically has a relatively weak market power, to control price movement, described using the structure-conduct-performance (SCP) for CPO mill industry [7]. A similar SCP approach that puts more focus on CPO-derivative cooking oil industry was reported [8]. CPO mills profitabilty is, at a higher degree, being influenced by CPO company's liquidity, instead of by company size or CPO market price, as demand tends to be inelastic against price, was also reported [9].

Despite being one of the largest CPO supplier country, Indonesia does not hold a clear monopoly over CPO market, as global trading tends to follow Amsterdam or Kuala Lumpur CPO market price. The Indonesian CPO production capacity that seems to have little influence on the market demand quantity, is considered as being decoupled, or stated as an exogenous variable).

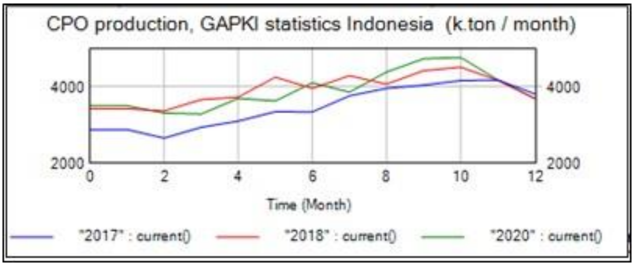


Figure 1. Seasonal nature of CPO production, typical (GAPKI, Indonesian palm oil industry 2017-2020, monthly data, reformatted, https://gapki.id/)

Implementing system dynamic methodology in this research through developing a dynamic model simulation was intended to address such commodity production issues, as similar (but not identical) system dynamic model, that was reported earlier [10]. The range of demand in the global market might be considered as elastic to CPO price. To some extent, a different model for Indonesian domestic CPO demand is assumed as being inelastic to the price. CPO production volume to meet sales-demand would not change significantly, despite sales-price varies a lot, as Indonesian domestic market is not considered as sufficiently large for being a market-maker at the global level, described above.

Further, parameters for mills productivity is represented by production amount, instead of price, as the industry profitability is not strongly influenced by the price level [9]. On the other hand, it was also mentioned that company liquidity (represented by current assets, or cash equivalent) seems to have a stronger influence on business profitability, to support future expansion options [9]. Therefore, company 'stock current asset CPO-mills (profitability)' variable is used for input to the feedback loop to the capacity expansion, or re-investment (while the level of CPO stock would be one of the feedback inputs). For the model developed, price is used only as a conversion factor, or a constant, to indicate the order of magnitude for CPO production amount in terms of financing for investment.

The problem statement is therefore on identifying variables, or factors, influencing the behaviour of the amount of CPO production, and CPO mills production capacity, that provide a relevant representation of CPO production dynamics in Indonesian market, by simulating a system dynamic model structure with proper input values.

Commodity production often involves a complex system, intertwining several operational parameters to determine the rate of production, installation capacity, costing/pricing issues, as well as other technical variables directly influencing the value and behaviour of those operating parameters dynamics. The approach for this research is to identify a minimum set of parameters, being sufficient to develop a proper dynamic model simulation to represent the commodity production system.

A simplified flow diagram to describe the approach in simulating the model for CPO production capacity expansion is provided in Fig.2 below.

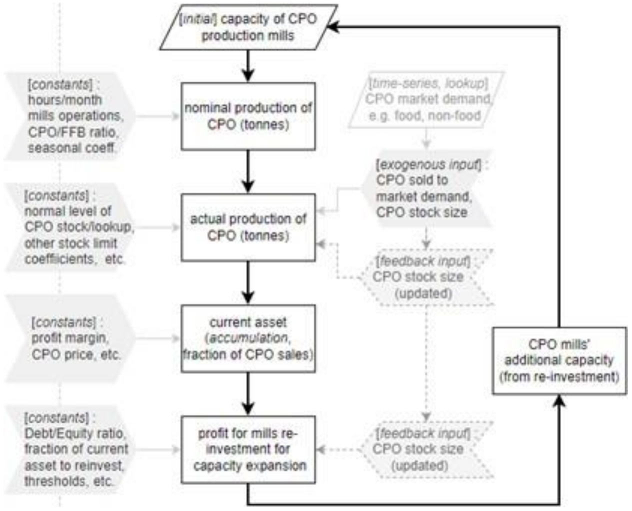


Figure 2. Flow diagram for a simplified approach in simulating the model loop for CPO production capacity expansion

The strength of system dynamics methodology that raises interest for this research is how the production capacity develops throughout the years, both historical and in the future. Having a limited number of operating parameters in CPO production model simulation would enable the modeler to focus on the primary behaviour of the system dynamics, while being able to reduce the computational reseources needed for dynamic simulation.

Technical issues identified in this research are limited availability of CPO market/production data, that properly represent the CPO industry dynamics in past years, or provide an adequate projection for coming years. With such a limited data at the macro level in the country, a system dynamic model would need to be developed that is quite straightforward, and sufficiently close to simulate the industry behaviour. While trying to avoid the model to rely heavily on such variables on micro level, such as sales price of CPO at different time/region (where data is highly variable), this research would employ several proxies for representing the tendency for increasing or reducing production quantity, and subsequently re-investing into production capacity asset in CPO mills.

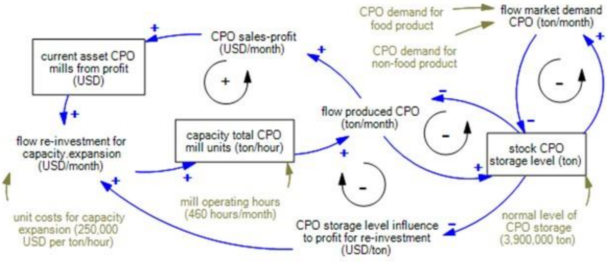
Basically, system dynamic simulation was intended to reproduce the system behaviour in a reasonable mannter, following typical cognitive behaviour among various players (either individual, or institution) in the market. Therefore, the model developed to represent CPO mills' production-capacity would need to identify several logical responses (feedback input) provided by certain variables, or components, throughout their interactions in the market.

Approach for this research has identified one variable "CPO storage" (or the level of CPO stock, in the national market), having relevant behaviour that often influences CPO production. Players in the market typically responded to the level of CPO stock, for adjusting their supply of CPO products (to meet the market demand signal, following their expectations, or their commercial experience). There are three types of responses to the level of CPO stock, (i) when CPO stock becomes higher than expected, (ii) when CPO stock is considered at its normal level, and (iii) when CPO stock is considered very low (or much lower than expected).

To these three types of responses, there are two sides of CPO storage, having behaviour relevant to the model simulation. The first is the amount of CPO supply (from CPO mill production-capacity <supply>), and the second is the amount of CPO demand (from buyers to the CPO market <demand>). The level of influence asserted by each side of the market players may change from time to time, producing dynamic behaviour to the system, in terms of the rate of change to the level of CPO stock.

Such a dynamic behaviour could represent the relationship between components and sections in the system, that was intended to describe certain influence of feedback input to the model simulation, preferably from a stock variable (such as CPO storage, in this case). Therefore, the model may define a certain amount of feedback as a function of the level of CPO stock (possibly as an inverse, for example: feedback input may decrease to a certain level, by gradual increase of CPO stock).

In short, the level of CPO stock could be closely related to the amount of sales from CPO mills. Such CPO stock data may serve as a proxy to the profit-making activities for business owners. It is represented by the dynamic hypothesis described as a causal loop diagram, in Fig.3.



(reinforcing and balancing/opposing feedback loops, indicated by '+' and '-' sign)

Figure 3. Causal loop diagram, CLD, palm oil mills, the dynamic hypothesis

Future growth of CPO mills production capacity, or the rate of investment to new construction of CPO mills, being related to the actual level of CPO stock, is investigated. Higher level of CPO stock, that indicates less CPO volume being sold, may reduce its business attractiveness to the new investment (challenges to increase CPO production capacity level, as being inversely proportional to the level of CPO stock), and vice versa. For example, during the last global crisis (Covid pandemic) just a few years ago, that significantly reduced product transaction volume, where the amount of palm-oil fruit harvest was much larger than the CPO demand. Challenge to the mill's business was tough as market plummeted, it became rather difficult to find sufficient buyers to take CPO volume from their on-site storage tanks, so that the level of CPO stock was kept high for several months, where such a dynamic price drops deeply reduced the mill's profitability.

In comparison with other commodity or energy markets such as petroleum, diesel fuel or coal are non-perishable products, fossil-based, that can be kept in storage for long time without significantly degrading its quality. CPO product storage, on the other hand, is similar to other perishable vegetable-based oil that has a limited period of time before its quality drops (so that large quantity of CPO product needs to be sold in a shorter period, for example by reducing its price to attract corporate buyers). Therefore, vegetable oil business profitability is often more sensitive to the market dynamics, that needs to be carefully managed.

3. Dynamic Model Development for CPO Mills Production-Capacity

3.1 Overall Dynamic Model for CPO Mills

For simulating the dynamic model for CPO mills production-capacity, three submodels #1, #2 and #3 were developed. The first submodel took data input from historical market demand (2015-2021), and 10 years projection for market demand, to put into the overall model simulation.This submodel #1 consists of one stock variable (level of CPO storage) and two flows (input and output of CPO flow, for simulating the CPO storage level). Importantly, it serves as both connecting the market demand input, and for decoupling the data for CPO production amount from the market demand data, throughout simulation period.

The second submodel for current asset accumulation presented the stock variable for current asset (accumulating values from CPO sales-profit, as difference value of cash-in/-out flow from CPO production activities), and re-investment outgoing flow, with a secondary outgoing flow to represent another stream of current asset for the mills' debt-service. Simulated result values from CPO stock variable (submodel #1 above) provides feedback input to this second submodel for calculating the amount of re-investment flow, which would subsequently be used as input data to the third submodel of CPO mills investment for production capacity expansion.

The third submodel put a stock variable for the CPO mills production capacity, at the national level. Inflow of re-investment (submodel #2 above) accumulates as CPO mills capacity, using the constant for unit-costs capacity expansion. The stock variable is used to determine CPO mills production amount, providing input values to the submodel #1.

All submodels #1, #2 and #3 were simulated in an integrated model structure in the following Fig.4.

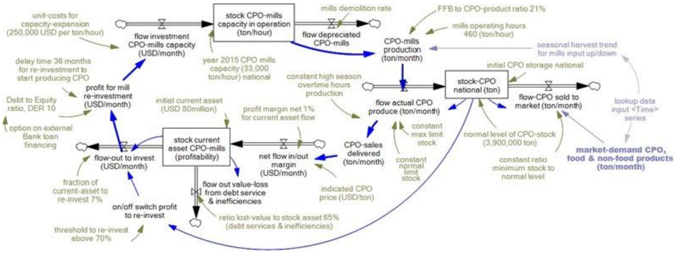


Figure 4. Overall system dynamic model

3.2 *Submodel Representation for Dynamic Simulation*

3.2.1 *Submodel #1 'Market Demand'*

Submodel #1 'Market Demand' intends to simulate impacts of changing market demand to the overall system's beaviour over time (BOT).

Following the research hypothesis above, the variable level of CPO stock zCSN serves as the proxy for representing market behaviour, that applies to variable yACP and yCSM. For each interval of zCSN value, a slightly different approach applies below.

The level of CPO stock zCSN falls into one of the following intervals, with a threshold representing the typical, or normal level of CPO stock qNLS. Two important thresholds are the medium limit qNLS, and the upper limit qNLS*2, described as follows, and in the next page:

Threshold qNLS = 4,000,000 ton.CPO limit, as a boundary between conditions 2b, 2c, 3b and 3c.

Threshold qNLS*2 = 8,000,000 ton.CPO upper limit, as a boundary between conditions 2a and 2b.

In model simulation, the upper limit of threshold qNLS*2 (or twice the typical qNLS value) is multiplied by an max limit constant qMLSL, to enable fine-tuning the upper limit (a bit lower than original threshold qNLS*2).

Also note that for calculating the amount of CPO sold to market, the threshold qNLS is multiplied by a constant for ratio minimum stock to normal level qRMSN, for fine-tuning the threshold to be lower than qNLS. Submodel #1 is illustrated in Fig.5, with both the variables and abbreviated versions for easier understanding and shorter descriptions.

Figure 5. Submodel #1 for market demand input, decoupling from simulated values of CPO production amount: (upper figure) with full notation, and (lower figure) abbreviated version

Each of the following equations apply for the range of stock 'zCSN' values, as below:

$$zCSN = INTEG(yACP\,\breve{}\,yCSM) \tag{1}$$

$$yACP = 0 \tag{2a}$$

$$yACP = vCMP * (qNLS * 2 * qMLSL\,\breve{}\,zCSN)/(qNLS * qNLSL) \tag{2b}$$

$$yACP = vCMP \tag{2c}$$

$$yACP = vCMP * qHSOH \tag{2d}$$

$$yCSM = ts.MDCP \tag{3a}$$

$$yCSM = ts.MDCP * zCSN/(qNLS * qRMSN) \tag{3b}$$

$$yCSM = 0 \tag{3c}$$

$$vCMP = zMCE * qFCPR * qMOH * tsSHTM \tag{4}$$

$$vCSD = yACP \tag{5}$$

Any of these conditions 2a to 2d applies to either one of equation 2a to 2b, as follows:
(condition 2a) if qNLS*2*qMLSL < zCSN
(condition 2b) if qNLS*2*qMLSL > zCSN > qNLS
(condition 2c) if qNLS > zCSN > qNLS/2
(condition 2d) if qNLS/2 > zCSN

Any of these conditions 3a to 3c applies to either one of equation 3a to 3c, as follows: (condition 3a) if zCSN > qNLS*qRMSN (condition 3b) if 0 < zCSN < qNLS*qRMSN (condition 3c) if zCSN = 0 (or zCSN < 0)

Submodel #1 serves as a decoupling condition/mechanism, from CPO market demand tsMDCP situation to CPO production yACP in simulating the system dynamics' primary loop (indicated by thick blue arrows in Fig.5). This decoupling was provided through the level of CPO storage zCSN behaviour, often being perceived as a buffer quantity, reducing seasonal production volatility, or managing sudden changes in market demand.

The feedback input from the level of CPO stock zCSN were described in submodel #1. This gives the option of using only one of these conditions, at each time-step for model simulation. Therefore, the simulation results may show such and adaptive-response to dynamic-changes in input/output values on each model's variables, for better maintaining the system stability.

For the magnitude of yACP, it may slowly approach zero when zCSN is higher than normal qNLS. This indicates the trend of difficulties for mills to produce CPO when the level of CPO stock is higher than typical values during normal times, described by the following conditions 2a to 2d:

- When the value of stock level zCSN is above the upper limit (twice qNLS value, multiplied by a max limit constant qMLSL), then the magnitude of actual CPO produced yACP is defined as zero (condition 2a);
- When the value of stock level zCSN is between the typical qNLS value and the upper limit (twice qNLS value, multiplied by a constant qMLSL), then the magnitude of yACP is slowly approaching zero (condition 2b);
- When the value of stock level zCSN is between half the qNLS value (qNLS/2) and qNLS, then the magnitude of yACP equals the normal CPO mills production capacity vCMP itself (condition 2c);
- The magnitude of yACP may increase above normal production vCMP (or yACP equals vCMP multiplied by a constant for high season overtime hours production qHSOH) when zCSN is less than half the qNLS level. This indicates the CPO mills tendency to increase production effort above normal when the level of CPO stock might become very low (condition 2d).

The feedback input from the level of CPO storage zCSN serves as a buffer, for either increasing or decreasing the production amount yACP. This feedback mechanism in submodel #1 structure is critical for modeling the amount of CPO sales, hence the profit-margin available for re-investment purpose, subsequently used for calculating the rate of production capacity increase in submodel #2 and #3.

Likewise, the conditions3a to 3c describes the magnitude of CPO sold to market yCSM:

- When zCSN is high (or at least above qNLS level multiplied by a constant for ratio minimum stock to normal level qRMSN), this is (condition 3a);
- The magnitude of yCSM may slowly approach zero when zCSN is lower than qNLS level multiplied by a constant qRMSN (indicating the trend of difficulties in getting CPO delivery, when the level of CPO stock became very low), this is (condition 3b);
- When CPO stock zCSN is zero, there is no CPO sold to market (yCSM equals zero, so that for the purpose of proper model simulation, a negative value of yCSM

value is not possible), this is (condition 3c).

3.2.2 Submodel #2 'Current Asset Accummulation'

Submodel #2 'Current Asset Accummulation' intends to estimate the amount of re-investment capital required to the CPO mills capacity expansion.

Submodel #2 takes into account the level of CPO stock zCSN value from submodel #1, described above. The amount of capital for re-investment yOI considers the logical causality: if the value zCSN exceeds a maximum threshold for investing qTIA for CPO stock level qNLS, then yOI is zero, described in (condition 9b) for (Eq.9b).Otherwise, it equals the level of current asset zCAM multiplied by certain fraction of current asset to reinvest qFCAI, described in (condition 9a) for (Eq.9a). Such system behaviours werealso described by the following conditions 10a and 10b:

- The condition for indicating business interest to increase capacity investment is represented as during high CPO production period (relatively low level of CPO stock below typical qNLS value multiplied by a maximum threshold for investing qTIA), this is(condition 10a);
- However, such willingness to re-invest tend to decrease, or possibly disappear, during period with low market demand (increasing level of CPO stock above typical qNLS value multiplied by a maximum threshold for investing qTIA), this is (condition 10b).

The variable 'stock current asset CPO mills (profitability)' zCAM in submodel #2, described in Fig.6, also serves as a buffer for calculating the amount of re-investment yOI, required for subsequent input variable yIMC in submodel #3 (for increasing CPO mills capacity zMCE).

Using the stock variable zCAM would reduce the volatility for simulation runs, compared to other alternative simulation using a flow variable such as CPO production amount (the level of variable 'stock' is considerably more stable, while the variable 'flow' often fluctuates a lot, throughout the simulation time-steps).Balancing an inlet (net-flow in/out margin) with an outlet (flow out value loss), gives the remaining outlet as intended (flow out to invest) from zCAM. Inlet flow is multiplied by a profit margin (1%, estimated being fairly low for primary commodity with persistent market demand, such as food/bulk-materials), while outlet flow is multiplied by an asset value loss (65%, estimated as fairly high for corporate expenses such as debt service and management/marketing/inefficiencies/other development costs). The remaining intended outlet flow from stock curent asset zCAM is therefore multiplied by a fraction of current asset to reinvestment activity (7%, being fairly low as investment amount is less consistent, compared to other corporate costs). In simulating the submodel #2, also note that the amount of remaining current assets available for re-investing (intended outlet flow) is not increasing very fast, hence avoiding the unrealistic exponential growth situation.

These equations apply for submodel #2, as described below (please also note that (Eq.9a) to (Eq.9b), and (Eq.10a) to (Eq.10b) might also applyas feedback inputs for the range of stock 'zCSN' values):

Figure 6. Submodel #2 for current asset accummulation, taking input of sales-profit, and providing output to the rate of re-investment: (upper figure) with full notation, and (lower figure) abbreviated version

$$zCAM = INTEG(yNIO \breve{} yLDI \breve{} yOI) \tag{6}$$

$$yNIO = vCSD * qPMCA * (1 \breve{} qRDP) * qICP \tag{7}$$

$$yLDI = zCAM * qRLDI \tag{8}$$

$$yOI = zCAM * vSPI * qFCAI \tag{9a}$$

$$yOI = 0 \tag{9b}$$

$$vSPI = 1 \tag{10a}$$

$$vSPI = 0 \tag{10b}$$

Any of these conditions 9a to 9b applies to either one of equation 9a to 9b, as follows: (condition 9a) if $zSCN > 0$ (condition 9b) if $zSCN < 0$ Any of these conditions 10a to 10b applies to either one of equation 10a to 10b, as follows: (condition 10a) if $zCSN < qNLS*qTIA$ (condition 10b) if $zCSN > qNLS*qTIA$

3.2.3 Submodel #3 'CPO Mills Production-Capacity Expansion'

Submodel #3 'CPO Mills Production-Capacity Expansion' intends to simulate the production-capacity expansion, for closing the feedback loop from submodel #2 back to submodel #1 (production, to meet market demand).

The submodel #3 considers typical CPO mills capacity-expansion investment decision that would take up to 36 months [11] until the mill start operations. This typically started from project development phase, project financing approval, to land preparation, major construction and equipment commissioning works, that often take a multiyear work approach), hence delay time qDISP was assumed to be 36 months, described in Fig.7. However, the first harvest from the plantation often started from year 4 or 5 anyway, as common practice in palm oil farming.

Financing such mill capacity-expansion is often implemented through project financing with commercial Bank loan, where its Debt-to-Equity ratio qDER was typically assumed to be 10. For each incremental capacity of 1 ton/hour, project investment needed for the variable qMDR is in the range of USD 200,000 – 250,000. Indonesian palm oil data indicated that total FFB processing capacity in all CPO mills was about 33,000 ton/hour, xMC.

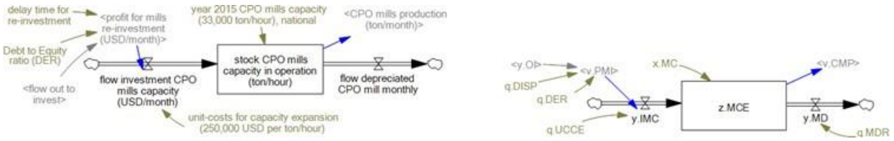


Figure 7. Submodel #3 for CPO mills production-capacity expansion, closing the loop from submodel #2 fback to submodel #1: (upper figure) with full notation, and (lower figure) abbreviated version

$$zMCE = INTEG(yIMC\breve{}\,yMD) \tag{11}$$

$$yIMC = vPMI * qUCCE \tag{12}$$

$$yMD = qMDR \tag{13}$$

$$vPMI = yOI * qDER * qDISP \tag{14}$$

The resulting accumulated stock of CPO production capacity zMCE data in submodel #3 is used for submodel #1 variable vCMP nominal CPO production, by multiplying zMCE with typical operating hours that may range between 12 to 16 hours per day, and often times exceeds those daily hours in high season months, as Haryati et.al. indicated [12], estimated asof 460 hours/month qMOH,while typical industry ratio [13] CPO/FFB is estimated as 21% qFCPR, also taking into account seasonal nature of FFB-harvest variability, tsSHTM.

The amount of capital re-investment, and its timing (occurrence interval, between each tresholds), is simulated in submodel #1 and #2 following certain pattern of CPO production strategy, in the following matrix.

The following Fig.8 are the graphical representations for variable yACP and yCSM, each described in Table 1: column (a1) for condition 2a to 2d, and column (a2) for condition 3a to 3c, respectively.

The vertical axis shows the value between 0 and 1, representing the fraction of CPO produced, or supplied to market (with regard to the normal CPO mills production capacity vCMP and the CPO market demand tsMDCP, respectively). The horizontal axis shows the interval between each threshold described in Table 1 above, where the value of 1 represents the level of CPO stock zCSN that equals the normal level of CPO stock qNLS (or zCSN = qNLS), hence the value of 2 represents qNLS*2 (or the upper limit of CPO stock).

Table 1. Matrix for CPO production/supply (column A1, A2), as a function of the level of CPO stock

Threshold, interval	(a1) CPO production, yACP	(a2) CPO supplied to market, yCSM
Very high level of CPO stock, zCSN > 2*qNLS* qMLSL	No CPO is produced This is (condition 2a), for (Eq.2a)	CPO supplied to market equals market demand (very little restriction to supply the market) This is (condition 3a), for (Eq.3a)
High level of CPO stock, zCSN >>> qNLS	CPO produced is gradually increased (slowly from yACP = 0, until yACP = vCMP) This is (condition 2b), for (Eq.2b)	
Medium level of CPO stock, zCSN is in the typical range of qNLS	CPO produced equals the normal CPO mills production capacity(yACP = vCMP) This is (condition 2c), for (Eq.2c)	CPO supplied to market is gradually reduced (slowly until yCSM =0) This is (condition 3b), for (Eq.3b)
Low level of CPO stock, zCSN < 50%*qNLS	CPO produced could be higher than the normal CPO mills production (adding extra operating hours to the mills) This is (condition 2d), for (Eq.2d)	No CPO delivered to market This is (condition 3c), for (Eq.3c)
Zero stock, zCSN = 0		

4. Discussion on the Overall Model Simulation

This research work on simulating the overall model was intended to establish the major feedback loop, that may represent historical growth of palm oil mill production capacity 'zMCE' (starting with initial value of CPO mill production capacity of 33,000 ton/hour in total, by year 2015 data 'xMC'). Historical data 'tsMDCP' for CPO market demand (2015–2021, exogenous data) was employed to drive the dynamic model simulation, by estimating the level of CPO stock 'zCSN' as a buffer variable. In turn, this buffer was used for controlling the amount of CPO production 'yACP' and the amount of re-investment 'yOI'. Such results influenced CPO production capacity increase 'yIMC', and the accumulated capacity 'zMCE' as a stock variable.

The nominal amount of CPO production 'vCMP' is therefore being re-calculated into actual CPO production 'yACP' (using equations with direct feedback from stock 'zCSN' and other relevant variables, constants), hence closing the overall loop. Except

Table 2. Matrix for capital re-investment (column B1), as a function of the level of CPO stock

Threshold, interval	(b1) Re-investment to expand capacity
Very high level of CPO stock, zCSN > 2*qNLS Medium to high level of stock, zCSN > qNLS	No re-investment of the mills' current asset This is (condition 10b), for (Eq.10b)
Low to medium level of stock, zCSN < qNLS	Re-investing a fraction of the mills' current asset, for capacity expansion This is (condition 10a), for (Eq.10a)

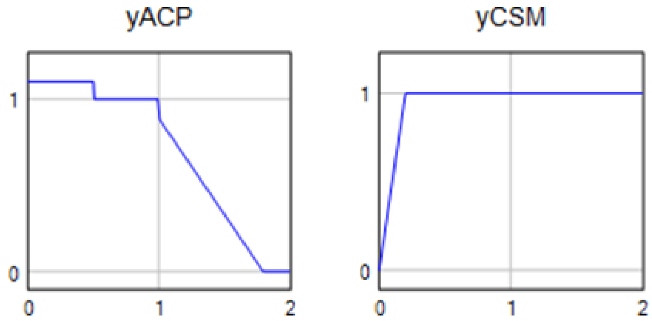


Figure 8. Graphical representation of each interval in Table 1: (left figure) for column (a1) variable yACP; (right figure) for column (a2) variable yCSM

for variable 'tsMDCP' as an exogenous data input, other variables described above were all endogenous, resulting from simulation runs. These results represented the system behaviour described in the above dynamic hypothesis.

Upon simulation results, two variables were used as comparison with historical data, as in Fig.9. The first was the amount of CPO production 'yACP' with historical market demand 'tsMDCP' data (modelled in a separate section), where the simulated 'yACP' was presented as accumulated value that fell within the range of accumulated 'tsMDCP' time series data. The second variable was 'zMCE' production capacity level with its historical data 'tsMCE', in which the simulated 'zMCE' was found within the range of 'tsMDCP' time series data.

Subsequently, close examination of the simulated 'yACP' production data revealed a periodic tendency (cyclical) behaviour of 'yACP' variable, that was balanced by another periodic behaviour of CPO storage level 'zCSN' that serves as a buffer, described in Fig.10 below. For example, when CPO production amount 'yACP' decreased, CPO supply to meet market demand was compensated by a corresponding change of storage level 'zCSN', for each time step in the simulation results. Such a complementary behaviour of 'yACP' and 'zCSN' was intended for maintaining a relatively smooth data results for market demand 'yCSM' (that corresponds to its

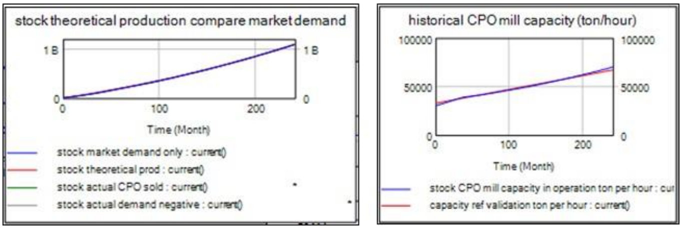


Figure 9. Comparison of simulated results: (left figure) CPO production 'yACP'; and (right figure) level of production capacity 'zMCE'

time series data 'tsMDCP'). The system dynamics structure was intended to employ stock variables (zCSN, zCAM and zMCE) for reducing data volatility and stabilizing the overall simulation results. Such model structure was intended particularly for estimating the amount of investment 'yOI', that was required to drive certain amount of production capacity increase 'yIMC' and its accumulated capacity 'zMCE', at the country level.

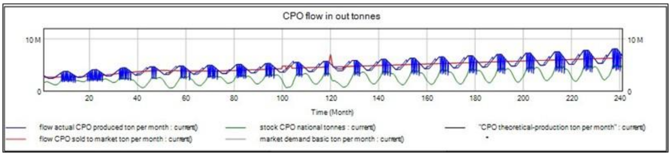


Figure 10. Simulated behaviour of CPO production 'yACP' and CPO storage level 'zCSN', compared to market demand 'yCSM'

Further, specifically for submodel #1 structure with 'zCSN' stock variable, the decoupling of historical market demand data 'tsMDCP' properly served the purpose of system dynamics modelling structure. The resulting production data 'yACP' was simulated from the growth of CPO mills production capacity 'zMCE', being endogenous variables, instead of direct reference to historical demand data 'tsMDCP' (an exogenous variable).

Without implementing such a decoupling structure by employing 'zCSN' variable, the system dynamics simulation might not reveal its feedback loop behaviour, failing to meet the purpose of dynamic simulation, as the exogenous variable 'tsMDCP' would directly influence CPO production data 'yACP'.These results indicated that the level of CPO storage 'zCSN' might be used as a proxy for representing the CPO supply-demand dynamics, fulfilling the dynamic hypothesis.

Another benefit of this modeling approach is by avoiding the needs to use a variable CPO price throughout the simulated period, as the input feedback from 'zCSN' was used for CPO production 'yACP' and investment amount 'yOI', for reproducing suitable dynamic behaviour as above. Substituting the needs for variable CPO price by using variable CPO storage level 'zCSN' may prevent uncertainties in future CPO price from influencing the simulation, when projecting the results into a longer simulation period, e.g. up to 240 months.

An additional trial run for imposing an external shock to the system, by artificially inflating the market demand data in a short period of time was simulated. It revealed corresponding changes in the CPO production 'yACP' and CPO storage level 'zCSN', for compensating such a sudden change in CPO demand. The system behaviour was considered as sufficiently robust, where these shock inputs could be absorbed, and properly buffered out by employing a stock variable in submodel #1 market demand and equations in other relevant variables, hence providing direct feedbacks to the simulated CPO production results.

5. Conclusion

The model structure with a closed feedback loop, from the level of CPO storage to the amount of investment for CPO production capacity was simulated. The result was able to reproduce a similar behaviour, in comparison with historical data for CPO market demand and CPO mills production capacity.

Two primary findings were that, first, the overall model simulation could be decoupled from the market data 'tsMDCP' (time series). Second, the level of CPO storage 'zCSN' might be used for a proxy, for simulating CPO production dynamics to reproduce the level of CPO production capacity 'zMCE', instead of using CPO price that could be highly volatile.

Projecting the results in a longer simulation period (up to 240 months) revealed a consistent system dynamics behaviour. Meanwhile, an external shock imposed to the simulated system indicated that the model was sufficiently robust. Such a stable result was achieved by implementing proper stock and flow variables/equations in the model structure, that was able to absorb, and distribute, sudden changes in demand, for a relatively short period of time.

Acknowledgement

The author would like to express their gratitude and appreciation to Universitas Indonesia for financing this study through the Dissertation Research Grant for Indexed International Publication Universitas Indonesia No.: NBK-1015/UN2.RST/HKP.05.00/2022.

References

[1] Leo Esaki. "New phenomenon in narrow germanium p- n junctions". In: *Physical review* 109.2 (1958), p. 603.

[2] Leo Esaki and Yuriko Miyahara. "A new device using the tunneling process in narrow pn junctions". In: *Solid-State Electronics* 1.1 (1960), pp. 13–21.

[3] AG Chynoweth, Ralph André Logan, and DE Thomas. "Phonon-assisted tunneling in silicon and germanium Esaki junctions". In: *Physical Review* 125.3 (1962), p. 877.

[4] AG Chynoweth, Ralph André Logan, and DE Thomas. "Phonon-assisted tunneling in silicon and germanium Esaki junctions". In: *Physical Review* 125.3 (1962), p. 877.

[5] Eric W. Greisen. *AIPS FITS File Format*. AIPS Memo Series. AIPS Memo 117, 2019.

[6] *KOMPAS MEDIA ONLINE*. Accessed: January 13, 2024. URL: https://www.kompas.com.

[7] *DETIK MEDIA ONLINE*. Accessed: January 13, 2024. URL: https://www.detik.com.

[8] Erlinda Muslim, Vivi Evertina, and Rahmat Nurcahyo. “Structure, conduct, and performance analysis in palm cooking oil industry in Indonesia using structure conduct performance paradigm (SCP)”. In: 25 (2008).

[9] Kifayatul Achyar et al. “PENGARUH HARGA CRUDE PALM OIL (CPO) SPOT, FIRM SIZE, LIQUIDTY, LEVERAGE TERHADAP PROFITABILITAS PERUSAHAAN KELAPA SAWIT YANG TERDAFTAR DI ISSI PERIODE 2015-2021”. In: (2022).

[10] Dennis Lynn Meadows. “The dynamics of commodity production cycles: a Dynamic Cobweb Theorem.” In: (1969).

[11] NEPCon OÜ. “Palm Oil Innovation Group Verification Report For Musim Mas Group In Indonesia”. In: (2020).

[12] Zainal Haryati et al. “Social life cycle assessment of crude palm oil production in Malaysia”. In: *Sustainable Production and Consumption* 29 (2022), pp. 90–99.

[13] Tuty Ningsih, Hari Gunawan, and Jhon F Parhorasan. “KAJIAN SISTEM PANEN TERHADAP POTENSI CPO (CRUDE PALM OIL) Di AFDELING I KEBUN TANAH RAJA PT. BAKRIE SUMATERA PLANTATION, Tbk.” In: *Jurnal Agro Estate* 5.2 (2021), pp. 122–128.