Multi-objective model of waste transportation management for crude palm oil industry

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Abstract. The crude palm oil industry is an agro-industrial commodity. The global market of this industry has experienced rapid growth in recent years, such that it has a strategic value to be developed for Indonesian economy. Despite these economic benefits there are a number of environmental problems at the factories, such as high water consumption, the generation of a large amount of wastewater with a high organic content, and the generation of a large quantity of solid wastes and air pollution. In terms of waste transportation, we propose a multiobjective programming model for managing business environmental risk in a crude palm oil manufacture which gives the best possible configuration of waste management facilities and allocates wastes to these facilities. Then we develop an interactive approach for tackling logistics and environmental risk production planning problem for the crude palm oil industry.

Keywords: Crude-Palm oil, Environmental Production Planning, Multi-objective programming, Modeling, sustainable optimization.

1. Introduction

Originally, the oil palm was found in the tropical rain forest of West Africa and was used as a source of oil and vitamins. Since then the oil palm tree had spread in many tropical countries in Asia, Africa and Latin America. Oil palm seeds of the Dura variety were introduced to Indonesia and Malaysia in 1848 and 1875, respectively. The oil palm cultivation in South East Asia, such as, in Indonesia, Malaysia and Thailand, produce about 80% of the world’s palm oil [1].

Palm oil is used in various food products, such as cooking oil, margarine, frying fats, shortenings, vanaspati, non-dairy creamer, etc. Palm oil is also used in non-food products. It can be substitute products derived from petrochemicals. Due to an increasing environmental awareness, these products have a bright future, particularly, in producing biodiesel.

Due to the increasing market demands and to stay competitive, palm oil companies should have production planning strategies. A plan which can be defined as the acquisition of resources needed and raw materials, as well as planning of the production activities and handling the waste. All of the above, meeting customer demand in the most efficient or economical way possible, i.e. minimizing total costs [2]. Determination of the optimal number of production became one of the key component for a successful production planning [3].

It is no doubt that the crude palm oil (CPO) industry plays an important role for economic development. However, it contributes to environmental degradation from both input and output sides of its production activities. From the input side, CPO mill uses much water in production process and
Waste can be classified by its source, which includes municipal solid waste (MSW), waste waters, specific industrial waste, and medical waste. In addition, it can also be distinguished by the degree of its hazardousness, ranging from organic residues of agricultural industry to highly dangerous nuclear waste.

This paper considers about waste management planning for the transportation and disposal of CPO industrial waste. Industrial waste handling is the final and critical step for industrial pollution control. It is also an important issue to cleaner production and sustainable development. Industrial ecosystems are the environmental friendly systems for industrial waste recycling, resembling the food chains, food webs and the nutrient recycles in natural environment [7]. In scientific terms it can be stated as, what is the trade-offs between environment burden and economic activities

On the normative and quantitative terms, these questions have led to the concept of trade-offs and efficient frontiers for business and the environment [8], [9]. The main idea is to determine the set of solutions in which it is not possible to decrease environmental burden or to increase total environmental quality of each environmental category, unless increasing the costs. From a methodological perspective, however, there is not much developed on determining such a frontier or assessing the trade-offs in sustainable logistics networks, despite the extensive existing literature in the field of multi-objective programming. In this paper we address an approach that is sounded to capitalize the decision maker’s most effective cognitive capabilities: visual representation. In order to explore the efficient frontier in feasible time (for the intractability of determining all extreme efficient solutions in a multi-objective linear program, see [10], [11], [12]. Management of waste has become an issue of critical importance during last decades mostly due to the complexity of waste streams and the steadily increasing produced volumes. Most often, the decision-making process towards efficient waste management requires the consideration of a significant number of usually conflicting criteria in order to come up with the optimal solution among alternative scenarios.

Multi-criteria decision-making (MCDM) or multiple-criteria decision analysis is a sub-discipline of operations research that explicitly considers multiple criteria in decision-making environments. MCDM is concerned with theory and methodology that can treat complex problems encountered in business, engineering, and other areas of human activity. A complex problem is characterized by incommensurate and conflicting criteria or objectives such as cost, performance, reliability, safety, productivity and affordability. In the presence of multiple criteria, a unique optimal decision for the problem does not exist but rather many or even infinitely many decisions are suitable [13].

Multi-criteria decision aid (MCDA) is an advanced field of operations research, which provides decision-makers (DMs) and analysts a wide range of methodologies, which are well suited to the complexity of decision problems [14].

Several MCDA methods have been proposed in recent years to help in selecting the best compromise alternatives rather than taking decisions based only on personal thoughts, views or experiences [15], [16]. Moreover, due to a rapid increase in existing technologies towards confronting waste management problems, decision-makers are forced to select among a wide spectrum of available alternatives. The growing environmental consciousness of society has also raised focus from a local to regional or global scale. In addition, the decision-making process towards efficient waste management requires the consideration of different parameters. To that end, MCDA methods have been proposed in
recent years as a means for helping decision-makers in selecting the best compromise among alternatives, as well as providing them a powerful tool towards convincing the public over the optimal waste management strategy. Applications of such multi-criteria methods have gained wide acceptance in the last few years over quantitative models, as the former embody many variables, quantitative as well as qualitative in their analysis [17]. MCDA provides a tool towards meeting the decision-makers’ needs, as well as gaining the widest possible social acceptance.

Waste management requires not only sound technical assessment of risk but also public participation, consultation and stakeholder dialogue on proposed solutions and associated risks. This is more evident for waste streams that need special treatment and certainly a wide public acceptance and consensus among stakeholders, such as radioactive waste management [18]. The usefulness of using one MCDA method in combination with life cycle analysis (LCA) modelling as a decision aid tool is considered most critical in the selection of an optimal management strategy in waste management problems [19].

MCDA methods present significant merits over other alternative decision-making tools, as well as a number of drawbacks. The pros and cons of the MCDA techniques are analytically addressed in the work of [20]. In brief, the key feature of MCDA techniques is its flexibility on the judgement of the decision-making team, which explores the optimal option by assigning performance scores and weights. In addition, MCDA techniques are able to evaluate qualitative) units [21]. Furthermore, MCDA techniques are used to identify either the single most preferred alternative, short-list alternatives for subsequent detailed analysis, rank different alternatives or to distinguish acceptable from unacceptable possibilities. Another important feature of MCDA is the performance matrix, where each row represents an option and each column describes performance of the option against each criterion. The performance matrix can be used when moving towards a final decision by comparing alternatives’ performances on a pair-wise basis for all different selected criteria.

On the contrary, there are also some drawbacks of the MCDA methods. One of the major drawbacks is those that are sensitive to uncertainties. For instance, general sources of individual uncertainties could come from data series uncertainties, uncertainty about the future, synergies and idiosyncrasies in the interpretation of ambiguous or incomplete information.

The objective of this paper is to propose a multiobjective programming model for managing business environmental risk in a crude palm oil manufacture which gives the best possible configuration of waste management facilities and allocates wastes to these facilities, to achieve the required objectives (minimization of cost, minimization of perceived risk (PR), minimization of environmental impact (EI) or a compromise between cost, PR and EI in such a way to limit its environmental consequences while increasing profitability.

2. Crude Palm Oil Manufacturing

2.1. Production Process

The two main products derived from the oil palm fruit are crude palm oil (CPO) and crude palm kernel oil (CPKO). CPO is obtained from the mesocarp (fiber) and CPKO is obtained from the endosperm (kernel). Each oil mill applies a conventional oil milling process, beginning with the steaming of fresh fruit bunches (FFB) under high pressure (sterilization) for a prescribed period of time to condition the fruits. The sterilized bunches are then threshed to separate the fruits from the bunch stalks. The fruits are subsequently pressed to obtain the crude oil. This oil–water mixture undergoes a separation process before the oil is purified and dried prior to storage. The water phase forms the bulk of the raw palm oil mill effluent, which is treated in a waste water treatment plant or a treatment pond.

2.2. Environmental Problems

The entire crude palm oil process does not need any chemicals as a processing aid. However, there are a number of environmental problems at the factories, such as high water consumption, the generation of a large amount of wastewater with a high organic content, and the generation of a large quantity of
solid wastes and air pollution. The waste generation (per ton FFB production) from the crude palm oil industry shows that only 22.8% of the raw material input consists of valuable products (CPO and CPKO). Palm oil mills also produce significant quantities of by-products/solid waste, such as empty fruit bunch, fibres, shell, decanter cake and ash from the boiler. Only 23% of raw materials are products, the rests are waste/ by-products. Most of the by-products can be reused in the production process or in other industries. Fibres (14%) are used as fuel in boilers to generate steam and energy, required for the mill operation. Shell (6%) and empty fruit bunch (EFB) (24%) are sold for use in other industries. However, there is a lot of solid waste that has to be treated before disposal. These wastes include 0.03 million ton/ year of decanter sludge and 0.05 million ton/ year of ash. The problems of solid waste management in factories are improper storage and handling of solid waste material and improper land application techniques or practices for solids waste. These wastes consequently cause bad smell and dust that affect the surrounding communities.

2.3. Existing Industrial Ecosystems in the Crude Palm Oil Industry
The crude palm oil industry has developed a number of industrial ecosystem practices for its waste recycling. The nature of these practices can be divided into in-plant industrial ecosystem (clean technology) options and possibilities for external waste exchange, which includes recycling of wastes between the industrial sector and other sectors such as agriculture. There are various technical options for an industrial ecosystem approach.

Environmental impact of palm oil industry can occur due to the following event. In order to produce CPO there are five stages involve: plantation, CPO mills, palm kernel oil mills, refinery factories, and CPO. Get the FFBs from palm oil plantation using transportation to a CPO mill. In here, kernel, CPO and bio-wastes are produced. Afterward kernel and CPO are transported to a place for processing kernel and CPO to get palm oil products. In market people buy this products and use them. Some part of the palm oil products are wasted as municipal waste [22].

3. Model Formulation
We define the notation used as follows.

| Symbol | Description |
|--------|-------------|
| J_{U_{ip}} | Amount of waste type i at source p |
| KLR | Risk factor |
| K_{upt} | Cost of segregation per unit quantity of waste in time step (t) |
| K_{U_{ip}} | Cost of processing unit quantity of waste I at source p in time step (t) |
| K_{R_{it}} | Cost recovered from the sale of unit quantity of processable waste type i in time step (t) |
| K_{U_{it}} | Cost recovered from the sale of unit quantity of reusable waste type i in time step (t) |
| K_{S_{it}} | Cost of storage per unit quantity of waste in time step (t) |
| B_{mb} | Capital cost for locating disposal facility (b) |
| B_{M_{fo}} | Capital Cost for locating processing facility fo |
| b | Disposal facility |
| D_{(p,fo)} | Distance between the source node (p) and processing facility (fo) |
| D_{(fo,b)} | Distance between the processing facility (fo) and disposal facility (b) |
| D_{(p,b)} | Distance between the source node (p) and disposal facility (b) |
| D_{r_{r,t}} | Distance between the source node (p) and reuse facility (p') |
| e | Total number of time steps |
| e^1 | Total number of time steps in which primary waste (u) can arrive back as waste after a cycle of reuse |
| p | Source node |
| p^1 | Reuse facility |
| V_{C} | Importance factor for chemical/component (c) |
| t | Time step |
| t^1 | Time step in which primary waste (u) going for reuse in time step (t) arrives back as waste on source nodes |
The model for the management of logistic CPO with life cycle based approach. There are three objectives to be attained within multi-time step. We define ‘time step’ as period of time, for which the waste generation and associated costs per unit quantity of weight, for a management of logistic activity (transportation, storage, disposal, etc.) remain constant. The time step could be year, months or any other unit of time for which the waste generation and associated management costs are assumed constant. The three objectives addressed consist of: (i) minimization of total logistic operational cost, (ii) minimization of waste environmental impact (EI), and (iii) minimization of total risk perceived (PR) by the people. Each of these objectives can be minimized individually or a compromise solution
using goal programming by assigning different weighting to each objective. The decision maker can assign different weightings to cost, PR and EI, depending on the governing socio-economic scenario. Various scenarios of different weightings to each of the objectives can also be analyzed to arrive at the various tradeoffs between these objectives.

The problem is subjected to the following constraints:

a. Mass balance of wastes at each node
b. Allowable capacities at various facilities.
c. Logical constraints at processing and disposal sites.

4. The Model

The problem is formulated as a multiobjective integer programming model. There are three objectives involve, i.e., Total of logistic operational cost, the cost related to risk, called perceived risk, and environmental impact of waste.

(A) Total of logistic operational cost.

$$TC_1 = \sum_{i=1}^{e} \sum_{p=1}^{n} \sum_{u=1}^{w} \left( N_{ip} - \sum_{b=1}^{Nb} N_{it(p-b)} \right) \times K_{ip}$$

This expression represents the cost of segregation at source node

$$TC_2 = \sum_{i=1}^{e} \sum_{p=1}^{n} \sum_{u=1}^{w} \left[ Nu(p) \times Ks(i) \times Rs(i) \times R_j \right]$$

Cost of storage at source node

$$TC_3 = \sum_{i=1}^{e} \sum_{b=1}^{n} \sum_{j=1}^{w} J_{js} \left[ N_{it(p-f)} \times K_{ij} \times D_{(p-f)} \right]$$

Cost of transportation of waste from source node to processing facilities and residue from processing facilities

$$TC_4 = \sum_{i=1}^{e} \sum_{p=1}^{n} \sum_{u=1}^{w} J_{fo} \left[ N_{it(p-f)} \times K_{ij} \right]$$

Representing the cost of processing waste at processing facilities

$$TC_5 = \sum_{j=1}^{J_{fo}} Bmfo \times Zfo$$

This is for Capital cost needed for locating processing facilities

$$TC_6 = \sum_{i=1}^{e} \sum_{p=1}^{n} \sum_{u=1}^{w} \left[ \sum_{p=1}^{w} N_{it(p-p')} \times K_{ip} + \sum_{p=1}^{w} N_{it(p-p')} \times K_{ip} \times D_{(p-p')} \right]$$

The transportation cost of reusable waste types to reuse facilities

$$TC_7 = \sum_{i=1}^{e} \sum_{p=1}^{n} \sum_{u=1}^{w} \left[ N_{ip} \times K_{ij} \times D_{(p-p')} \right]$$

Another transportation cost for some portion of waste from source nodes to disposal facilities.
\[ TC_8 = \sum_{b=1}^{NB} \left[ BM_b \times Z_b \right] \]  

(8)

Capital cost for locating disposal facilities

\[ TC_9 = \sum_{i=1}^{e} \sum_{b=1}^{NB} \sum_{p=1}^{n} \left\{ \sum_{i=1}^{w} N_{it(p-b)} \right\} \times K_{ib} \]
\[ + \sum_{i=1}^{e} \sum_{b=1}^{NB} \sum_{p=1}^{n} N_{it(p-b)} \sum_{f=1}^{J_p} \left( J_p \sum_{p=1}^{n'} N_{it(p-f)} \right) \times K_{bt} \]  

(9)

Representing the cost of waste disposal

\[ TC_{10} = -\sum_{i=1}^{e} \sum_{b=1}^{NB} \sum_{p=1}^{n} \sum_{f=1}^{J_p} \left[ N_{it(p-f)} \times Kru_{it} \times R_{it} \right] \]  

(10)

This is for the cost recovered from the sale of recyclable portion of generated waste, therefore there is a negative sign.

\[ TC_{11} = -\sum_{i=1}^{e} \sum_{b=1}^{NB} \sum_{p=1}^{n} \sum_{p'=1}^{n'} \left[ N_{it(p-p')} \times Ku_{it} \right] \]  

(11)

Another cost recovered from the sale of reusable portion of generated waste.

(B) Total perceived risk (PR)

\[ PR_i = \sum_{i=1}^{e} \sum_{b=1}^{NB} \sum_{p=1}^{n} \sum_{f=1}^{J_p} \left[ N_{it(p-f)} \times FRA_{it} \times KLR \right] \]  

(12)

This is an expression for risk due to transportation of waste from generation nodes to processing facilities

\[ PR_2 = \sum_{i=1}^{e} \sum_{b=1}^{NB} \sum_{p=1}^{n} \sum_{p'=1}^{n'} \left[ \left( \sum_{i=1}^{w} N_{it(p-p')} \times FRA_{(u)} \right) \times KLR \right] \]  

(13)

Risk due to transportation of reusable portion of waste to reuse facilities

\[ PR_3 = \sum_{i=1}^{e} \sum_{b=1}^{NB} \sum_{p=1}^{n} \sum_{p'=1}^{n'} \left[ N_{it(p-b)} \times FRA_{it} \times KLR \right] \]  

(14)

Risk due to transportation of non-reusable waste from source nodes to disposal

\[ PR_4 = \sum_{i=1}^{e} \sum_{b=1}^{NB} \sum_{p=1}^{n} \sum_{p'=1}^{n'} \left[ N_{it(p-b)} \times FRdis_{b} \times KLR \right] \]  

(15)

PR due to transportation of waste directly going to disposal without segregation

\[ PR_5 = \sum_{i=1}^{e} \sum_{p=1}^{n} \sum_{p'=1}^{n'} \left[ \left( FRA_{i} - \sum_{b=1}^{NB} N_{it(p-b)} \right) \times FRseq.p_i \times KLR \right] \]  

(16)

Risk at source nodes due to segregation

\[ PR_6 = \sum_{i=1}^{e} \sum_{p=1}^{n} \sum_{p'=1}^{n'} \left[ N_{it(p)} \times Frsit_{(p)} \times FRSi.p_i \times KLR \right] \]  

(17)

Risk occurring at source nodes due to storage
\[ PR_j = \sum_{t=1}^{w} \sum_{b=1}^{N_b} \left[ \sum_{p=1}^{n_j} \left( \sum_{i=1}^{n} N_{it(p-b)} \times FRdis_i \times KLR \right) \right] \]

\[ + \sum_{t=1}^{w} \sum_{b=1}^{N_b} \left[ \sum_{p=1}^{n_j} \left( \sum_{i=1}^{n} N_{it(p-b)} + J_{ip} \times FRdis_i \times KLR \right) \right] \]

Risk at disposal facilities due to waste

\[ PR_b = \sum_{t=1}^{w} \sum_{p=1}^{n_j} \sum_{i=1}^{n} \left[ \sum_{c=1}^{cn} N_{it(p-fo)} \times FRo \times KLR \right] \]

Calculating risk at processing facilities

Risk at reuse facilities

(C) Total impact or risk of the environment

\[ EI = \sum_{t=1}^{w} \sum_{b=1}^{N_b} \left[ \sum_{i=1}^{n_j} \left( \sum_{p=1}^{n} N_{it(p-b)} \times Ju \times V \right) \times Pk_{(b)} \right] \]

\[ + \sum_{t=1}^{w} \sum_{b=1}^{N_b} \left[ \sum_{i=1}^{n_j} \left( \sum_{p=1}^{n} N_{it(p-b)} + J_{ip} \times FRpu \times P \right) \times Ju \times V \times Pk_{(b)} \right] \]

Constraints

(a) Mass balance for primary waste type going for reuse in time step \( t \)

\[ \sum_{p=1}^{n_j} \sum_{i=1}^{n} N_{it(p-b)} = \sum_{p=1}^{n_j} \sum_{i=1}^{n} N_{it(p)} \quad \forall t, i \]

(b) Mass balance for waste arriving at source nodes

\[ N_{itp} + \sum_{j=1}^{\epsilon} \sum_{i=1}^{n_j} N_{itp} = N_{itp} \quad \forall t' = t, \forall p, i \]

(c) Mass balance at source nodes

\[ \sum_{t=1}^{w} \sum_{i=1}^{n_j} N_{itp} = \sum_{t=1}^{w} \sum_{b=1}^{N_b} \left( \sum_{i=1}^{n_j} N_{it(p-b)} \right) \]

\[ + \sum_{t=1}^{w} \sum_{i=1}^{n_j} N_{it(p-b')} + \sum_{j=1}^{\epsilon} N_{it(p-fo)} \quad \forall p \]

(d) Mass balance at processing facilities

\[ \sum_{p=1}^{n_j} \sum_{i=1}^{n} N_{it(p-fo)} \times (1 - R_{it}) = \sum_{p=1}^{n_j} \sum_{i=1}^{n_j} N_{it(p-fo-b)} \quad \forall fo, t \]

(e) Capacity constraint at processing facilities
Logical constraint at processing facilities
\[ \sum_{i=1}^{n} \sum_{p=1}^{w} N_{ut(p-fo)} \leq \text{Cap} \cdot fo \cdot t \quad \forall fo, t \] (26)

(f) Logical constraint at disposal facilities
\[ \left[ \sum_{i=1}^{\epsilon} \sum_{p=1}^{n} \sum_{p=1}^{w} N_{ut(p-fo)} \right] / \sum_{i=1}^{\epsilon} \sum_{p=1}^{n} N_{ut(p)} \leq Zfo \leq \sum_{i=1}^{\epsilon} \sum_{p=1}^{n} \sum_{p=1}^{w} N_{ut(p-fo)} \quad \forall fo \] (27)

(g) Capacity constraint at disposal facilities
\[ \sum_{j=1}^{J} \sum_{i=1}^{n} N_{it(fo-b)} + \sum_{p=1}^{n} \left( \sum_{i=1}^{w} N_{it(p-b)} \right) \leq \text{Cap} \cdot b \cdot t \quad \forall b, t \] (28)

(h) Logical constraint at disposal facilities
\[ \left[ \sum_{i=1}^{\epsilon} \sum_{j=1}^{J} \sum_{i=1}^{n} N_{it(fo-b)} + \sum_{p=1}^{n} \left( \sum_{i=1}^{w} N_{it(p-b)} \right) \right] \leq Zb \leq \sum_{i=1}^{\epsilon} \sum_{j=1}^{J} \sum_{i=1}^{n} N_{it(fo-b)} + \sum_{p=1}^{n} \left( \sum_{i=1}^{w} N_{it(p-b)} \right) \quad \forall b \] (29)

(i) Capacity constraint at reuse facilities
\[ \sum_{p=1}^{n} \sum_{i=1}^{w} N_{ut(p-p^{'})} \leq \text{cap} \cdot p^{'}, t \quad \forall p^{'}, t \] (30)

(j) Logical constraint
\[ Zfo = 0 \quad \text{or} \quad 1 \]
\[ Zb = 0 \quad \text{or} \quad 1 \]

5. The Algorithm
The proposed interactive algorithm consists of the following three steps.
Steps 1. Determine an initial (weak) efficient solution.
Steps 2. Show the solution to the decision maker (DM). If DM is satisfied with the solution,
   Stop: otherwise, ask the DM to specify a new reference point \( \bar{f}_i \), using Analytic Hierarchy
   Process (AHP) and go to step 3.
Steps 3. Based on the values of \( \bar{f}_i \) and \( f_k \) (the last solution), solve

\[
\max y
\]

subject to
\[
\begin{align*}
  f_i(x) - (\bar{f}_i - f_k)y \geq 0, & \quad f_i(x) - (\bar{f}_i - f_k)y \leq 0, \\
  xX & \leq \bar{f}_i, \\
  y & \geq 0
\end{align*}
\]

where \( y \) is a scalar.
and find a new intermediate weak efficient (or efficient)
solution \( f_i(x) \); go to Step 2.

6. Conclusions
Managing business environmental risk in agro-industry consists of making the production process
more efficient in such a way as to limit its environmental consequences while increasing profitability.
In this paper we present a multi-objective integer programming model for managing business environmental risk in a crude palm oil manufacture which consists of making the production process more efficient in such a way to limit the impact of environmental consequences and to meet the investment risk (perceived risk), and then we propose an interactive algorithm for solving the model.

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