Decision support system model for total cost and environmental impact: a case study of rice packaging in Thailand

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ABSTRACT

This study aims to incorporate a life cycle assessment (LCA) technique with multi-objective linear programming (MOLP) into practice through a case study of a rice packaging system in Thailand. The flexible packaging system chosen for the study is a CPP/LLDPE (cast polypropylene/linear low density polyethylene) bag of rice. The incorporated model is intended to determine an optimal usage of raw materials for rice package manufacturing. The decisions were as the consequence of minimization of two trade-off objectives: total cost and global warming potential. The results gained from this study show that the developed model could be used as a decision-support tool to yield a solution that is a compromise between cost and environmental considerations based on the manufacturer's preference and constraints. The optimal value of total cost and global warming potential are $US 6012.23 (equivalent to 192391.34 THB; $US 1 = 32 THB) and 2791 kg CO_2 eq, respectively. To this end, the slight improvement of lowering total cost and decreasing global warming potential at 0.1% and 1.5%, respectively, is below their typical values incurred in actual production.

Keywords: flexible packaging, total cost, global warming potential, life cycle assessment, multi-objective linear programming

1. Introduction

The basic functions of food packaging are not only to contain the food and provide consumers with information on ingredient and nutrition, but also to protect and preserve food products from outside influences and damages. Presently, there are many innovative packaging materials that are used for food products. However, plastic has gained more attention as the most common packaging material. This is because plastics can have various forms and applications, such as films and sheets, bags, pouches, and bottles. Plastics in flexible form are inexpensive and light-weight with a wide range of characteristics, including flexibility, heat sealability, and ease of print, and can be integrated into production processes where the package is formed, filled and sealed in the same production line (Marsh and Bugusu 2007). More than 90% of flexible packaging is made of plastics, compared to only 17% of rigid packaging (Raheem 2012). In Thailand, demand on the flexible packaging industry is expected to grow in response to the continuous expansion of the food industry, as flexible packaging is increasingly used to replace rigid packaging (Plastics Institute of Thailand 2012).

The environmental impact of packaging has become an important issue of society. This is due to a drastic accumulation of packaging waste becoming a major disturbance for life today. Directives and regulations for packaging wastes have been intensively enacted in an attempt to alleviate the environmental problems and thus inevitably being barred in many countries. As a result, manufacturers have gone on a quest for a good packaging solution for their products. One plausible action contrived on a technological development and innovation movement purposely depleted resource consumption but conversely elevated pollutants in the environment. Also, subduing environmental problems with this innovation may subsequently cause manufacturers relevant costs to increase and that can hurt business competition and profit achievement as a whole. This conflict of interest lead to manufacturer difficulties in decision making where simultaneous goals of economic and environmental aspects are being taken into account and the best alternative is not yet clearly determined (Pieragostini et al. 2011).

Life cycle assessment (LCA) is a technique used for identifying and quantifying the environmental performance of a product or process throughout its life cycle (cradle-to-grave) (Azapagic and Clift 1999). Several studies have employed LCA as a tool for determining appropriate packaging used in different applications. These include a comparative study on environmental impact generated by retort sterilization for glass jars, over the aseptic process for plastic containers (Humbert et al. 2009), and an environmental analysis of the entire life cycle of coffee and butter packed in flexible packaging systems (Büsser et al. 2009). Others are an evaluation of environmental impact of packaging systems for canned tuna meat (Poovarodom et al. 2011); a comparative study on environmental impact of strawberry packaging systems: bio-based polylactic acid (PLA) and petroleum-based polyethylene terephthalate (PET) and polystyrene (PS) clamshell containers (Madival et al. 2009). In addition, the single use thermoform boxes made from PS, PLA and PLA/starch was also studied (Suwanmanee et al. 2012).

Normally, the relationship between inventory data and impact category indicators of LCA methodology is linearly expressed by characterization factors, as follows:

$$E_j = \sum_i Q_{ij} m_i \qquad \text{Eq. 1}$$

where E_j is the indicator for impact category j; m_i is the quantity of emission pollutants i; Q_{ij} is the characterization factor that links emission pollutants i to impact category j (Pennington et al. 2004). However, this technique is based on unconstrained human economic activities, such as market demand, material availability and production capacities (Azapagic and Clift 1998). Therefore, the lack of information on economic effect is a major shortcoming of LCA.

As mentioned, decision-making incorporating environmental consciousness with economic cost for packaging solutions should be considered. An appropriate solution, comprising both environmental and economic aspects, in a packaging system can lead to manufacturer satisfaction. The objective of this study is to present the developed model incorporating life cycle assessment (LCA) technique and multi-objective linear programming (MOLP) for a rice packaging system in Thailand as a case study, aimed at combining two objectives: low total cost and decreased global warming potential.

Linear programming (LP) is based on a linear relationship subject to constraint models. This technique is usually used for solving economic problems and is formulated as follows:

$$Min\ Z = \sum_{j=1}^{J} c_j x_j \qquad \text{Eq. 2}$$

$$s.t. \sum_{j=1}^{J} a_{ij} x_j = or \geq or \leq b_i \qquad i = 1, 2, \ldots, I \qquad \text{Eq. 3}$$

$$and\ x_j \geq 0 \qquad j = 1, 2, \ldots, J \qquad \text{Eq. 4}$$

where Eq. 2 represents an objective function and Eq. 3-4 are linear equality or inequality constraints in the system. The objective function Z is a value of overall measure of performance (e.g. total cost); variable x_j is a level of activity j; coefficients c_j are the constant values of performance resulting from activity j; coefficient a_{ij} is the amount of resource i consumed by each unit of activity j; coefficient b_i is the right hand side or limitation of resource i that is available for allocation to activities (Azapagic and Clift 1998; Hillier and Lieberman 2001).

Multi-objective linear programming (MOLP) is the LP problem involving multiple objective functions. Thus, MOLP allows the problem where more than one optimization criteria needs to be satisfied (Ragsdale 2007).

2. Methods

2.1. LCA model

The goal of this study is to develop a multi-objective linear programming (MOLP) model by incorporating a life cycle assessment (LCA) technique. Optimality the use of raw materials for rice package manufacturing is determined as a decision considering variables that are the consequence of a trade-off between two objectives. Minimization of total cost for production and minimization of global warming potential are considered two such objectives.

The model system boundary (as shown in Figure 1) involves the acquisition of raw materials, transportation of raw materials and manufacture of the packaging (cradle-to-gate). In addition, packaging materials, including paper core, oriented polypropylene (OPP) tape and polyethylene (PE) film wrap that are required for packing processes are included in the study.

The flexible packaging system chosen for this study is a multi-layer of cast polypropylene/linear low density polyethylene (CPP/LLDPE) bag of rice. A 5 kg package size is used due to it being the most common size of rice products in Thailand. Finished packaging is in the form of bags on a roll (as shown in Figure 2) where the package can be formed, filled and sealed in the same automatic machine. Thus the functional unit is specified as 12,000 m of bags on a roll (a minimum quantity of production).

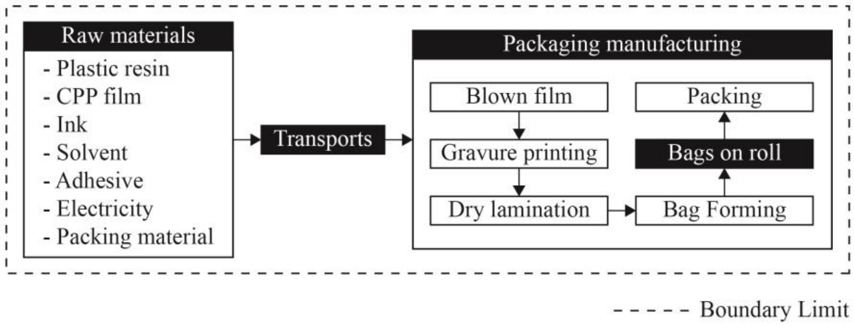

Figure 1. System boundary of the MOLP model.

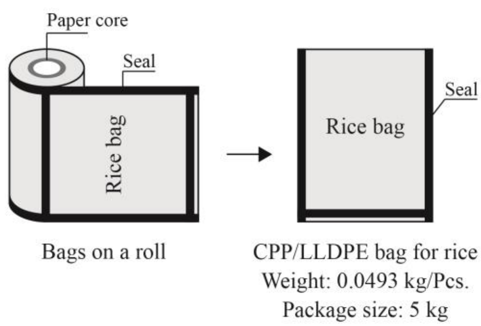

Figure 2. Feature of bags on a roll.

LCA is the most widely acceptable method to assess the environmental impact of a product or process throughout its life span, from cradle-to-gate or cradle-to-grave (Suwanmanee et al. 2012). This study is carried out using life cycle methodology in compliance with ISO 14040 (2006): Environmental management - life cycle assessment - principles and framework.

Life cycle inventory (LCI) data of CPP/LLDPE rice bags was collected from packaging manufacturers. Primary data of input materials, energy consumption, output products, as well as waste generated were collected for each main activity in the production line. The production process includes film blowing, printing, laminating, bag forming and packing. The transportation distance, including vehicle type, for the raw materials is provided (as shown in Table 1). In this study, an assumption on one-way transportation with 100% loading is made for the delivery of raw materials to the packaging manufacturer.

Table 1. Transportation data of raw materials for packaging production

Raw material	Vehicle type	Distance (km)
Plastic resin type A-D	Truck (6 wheels)	130
Plastic resin type E	Truck (6 wheels)	40
Printing cylinder	Truck (4 wheels)	100
CPP film	Truck (6 wheels)	110
CMYK ink	Truck (6 wheels)	100
Other ink	Truck (4 wheels)	50
Solvent	Truck (6 wheels)	50
Adhesive	Truck (4 wheels)	80
Paper core	Truck (4 wheels)	20
OPP tape	Truck (4 wheels)	50
PE film wrap	Truck (4 wheels)	20

Impact assessment is an important phase in LCA framework (ISO 14040 2006) for evaluating the significance of potential environmental impact based on the results of LCI. In this study, impact category of global warming potential (GWP) is chosen as it is relevant to the environmentally important emissions from the production of flexible packaging. The life cycle impact assessment was performed using the CML 2 Baseline 2000 method. Secondary data for emission factor was obtained from the supplier, Thai national LCI database (Thailand Greenhouse Gas Management Organization 2013) and peer-reviewed literature - namely, emission factor of printing cylinder (Ponnak 2011).

In this study, manufacturing cost is classified into four categories: direct raw material cost, direct labor cost, overhead cost and transportation cost. Primary data of direct raw materials cost, machine capability and overhead cost - for example, indirect raw material, indirect labor, depreciation of machine and building, electricity, and others, are approximated and provided by the packaging manufacturer. Direct labor cost is based on the secondary data of minimum wage (Ministry of Labor 2013) and the primary data of number of laborers in each activity of the production line and was obtained from the packaging manufacturer. In addition, secondary data of transportation cost was obtained from the database of cost for freight truck (Department of Land Transport 2009).

A number of constraints can be defined according to LCI as well as specification data of each activity in the production line. First, mass balance is carried out to define the mass balance constraints. This step is normally done in the LCI phase. Second, raw material usage for the CPP/LLDPE rice bags in each activity is limited in compliance with the production capability and performance. Therefore, these constraints can be defined as either equality or inequality. Lastly, the output products in each activity are limited by the functional unit of this study.

2.2. MOLP model

The MOLP model is incorporated with the life cycle assessment (LCA) technique to enable a workable combination of two objectives: minimized total cost for production and minimized global warming potential. The main steps to develop the MOLP model are (Ragsdale 2007)

- Implementing the MOLP model;
- Determining target value for the objectives;
- Determining weighted percentage deviation for the objectives;
- Defining the MINIMAX objective;
- Implementing the revised model and solving.

From the collected data, as discussed in section 2.1, the mathematical model of this study can be formulated as the following.

The raw material usage in each activity of the production line is defined as a decision variable, where the variable x_{ij} represents the quantity of raw material type i in activity j (kg or rolls); i = 1, 2, …, I and j = 1, 2, …, J (as shown in Table 2). In addition, the maximum of weight percentage deviation from target values (Q) is defined as the additional decision variable.

Table 2. List of raw material and activity.

j	Activity	x_{ij}	Raw material
1	Film blowing	x_{11}	Plastic resin type A
		x_{21}	Plastic resin type B
		x_{31}	Plastic resin type C
		x_{41}	Plastic resin type D
		x_{51}	Plastic resin type E
2	Printing	x_{12}	Printing cylinder
		x_{22}	CPP film
		x_{32}	CMYK ink
		x_{42}	Other ink
		x_{52}	Solvent type A
		x_{62}	Solvent type B
		x_{72}	Solvent type C
3	Laminating	x_{13}	Adhesive component A
		x_{23}	Adhesive component B
		x_{33}	Solvent type C
4	Bag forming	x_{14}	Paper core
		x_{24}	OPP tape
5	Packing	x_{15}	PE film wrap

Two objective functions, including minimized total cost and minimized global warming potential can be formulated as follows:

$$Min\ Z_1 = \sum_{j=1}^{J} c_{ij} x_{ij} \qquad \text{Eq. 5}$$

$$Min\ Z_2 = \sum_{j=1}^{J} e_{ij} x_{ij} \qquad \text{Eq. 6}$$

where Z_1 is the optimal value of minimized total cost ($US); c_{ij} is the unit cost of raw material ($US/kg), labor ($US/hr) or overhead ($US/hr) resulting from raw material type i in activity j; Z_2 is the optimal value of minimized global warming potential (kg CO_2 eq); e_{ij} is the emission factor of raw material (kg CO_2 eq/kg), electricity (kg CO_2 eq/kWh) or transportation (kg CO_2 eq/ton.km) resulting from raw material type i in activity j. However, it is important to note that these objective functions are subsequently are transformed according to the additional constraints of weighted percentage deviation from target values. Thus the MINIMAX objective function will be defined as a new objective function of MOLP model:

$$Min\ Q \qquad \text{Eq. 7}$$

$$w_1\left(\frac{Z_1 - t_1}{t_1}\right) \leq Q \qquad \text{Eq. 8}$$

$$w_2\left(\frac{Z_2 - t_2}{t_2}\right) \leq Q \qquad \text{Eq. 9}$$

where Eq. 7 represents an objective function and Eq. 8-9 are additional constraints of weighted percentage deviation from target values. Q is the maximum of weight percentage deviation from target values; the target value t_1 is the optimal value of minimized total cost obtained in single-objective optimization ($US); w_1 is importance weight of minimized total cost; the target value t_2 is the optimal value of minimized global warming potential that is obtained in a single-objective optimization (kg CO_2 eq); and w_2 is importance weight of minimized global warming potential. The weight factors are based on the manufacturer satisfaction. First, weighting factors equal to one are used to yield the same importance of minimized total cost and minimized global warming potential. Later, different relative relevance is considered by adjusting these factors (Pieragostini et al. 2011). In this case, the weight of importance of minimized total cost and minimized global warming potential are defined as 4.6 and 2.4, respectively.

The constraints maintain the mass balance in each activity of the production line. Thus, the sum of all input raw materials must be equal to the total output products, as follows:

$$\left(\sum_{j=1}^{J} x_{ij}\right) - b_j = 0 \qquad \text{Eq. 10}$$

where b_j is the output products from activity j (kg).

This constraint maintains the performance of output products in each activity of the production line. The limitations of raw material usage are defined as equality and inequality constraints, as follows:

$$x_{ij} \geq a_{ij}\left(\sum_{j-1}^{J} x_{ij}\right) \qquad \text{Eq. 11}$$

$$x_{ij} = d_{ij} \qquad \text{Eq. 12}$$

An inequality constraint of raw materials that can be optimized by the MOLP model is expressed in Eq. 11. An equality constraint of printing cylinder, CPP film and packing materials that cannot be optimized by the MOLP model are expressed in Eq.12. In addition, a_{ij} is the minimum percentage of raw material type i in activity j (%), and d_{ij} is the constant quantity of raw material type i in activity j per functional unit (kg).

This constraint maintains the relationship of output products and the functional unit of this study. The limitation of output products can be formulated as follows:

$$b_j = f_j \qquad \text{Eq. 13}$$

where f_j is the limitation of output products from activity j (kg).

The mathematical model is formulated on excel spreadsheets with the addition of solver add-ins (Excel's Solver). The optimality of raw material usage as decision variables for the CPP/LLDPE of rice bag manufacturing is determined as the consequence of the trade-off relationship between two objectives: minimized total cost for production and minimized global warming potential.

3. Results

According to the developed MOLP model, economic cost and global warming potential were calculated for each activity in the production of CPP/LLDPE rice bag to identify feasible usage of raw material while simultaneously minimizing total cost and global warming potential. The optimal solution obtained can serve as a basis to affect the improvement of packaging production.

First, the results of objective functions (Eq. 5-6) are obtained and then normalized to the optimal values of each objective. This can be done by a single optimization of one objective function while neglecting the other. Thus the target values of the two objectives - total cost and global warming potential - are found to be $US 6000.39 and 2780 kg CO_2 eq, respectively. However, it should be noticed here that when the total cost decreases to reach the feasibly minimum value of $US 6000.39, the global warming potential is 0.5% above its target value. Similarly, when the global warming potential decreases to reach the feasibly minimum value of 2780 kg CO_2 eq, the total cost is 1.2% above its target value. These two objectives are in direct conflict with each other. That is, reaching lower levels of global warming potential is associated with incurring greater levels of total cost for the production (Figure 3).

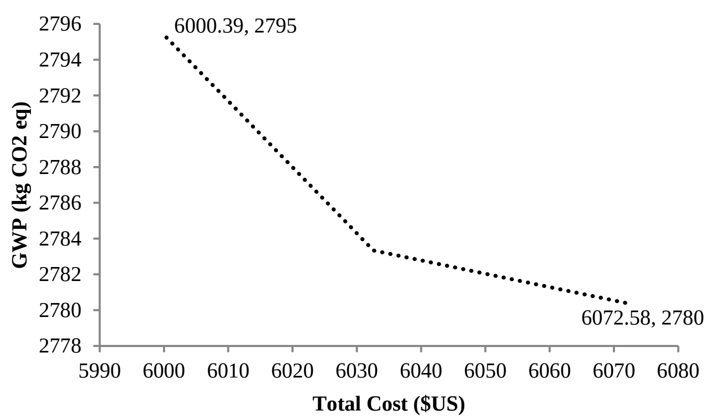

Figure 3. Trade-off relationship between GWP and total cost.

Therefore, the MINIMAX objective is applied to explore the loci on the edge of the feasible region where both objectives can compromise. In the case of the same weight factor (equal to 1) being applied to each objective, to indicate the same level of importance, the result of the MOLP model shows a slight increase in both objectives, approximately 0.3% above the target values. The optimal values of total cost and global warming potential are found to be $US 6018.27 and 2789 kg CO_2 eq, respectively (Table 3). However, it is not usual for industry to consider the cost issue to be of less importance to the decision-making process than the environmental impact. Thus, the weight importance factors of both total cost and global warming potential in this study are adjusted to 4.6 and 2.4, respectively. According to these weights, the optimal value of total cost and global warming potential are shifted to $US 6012.23 and 2791 kg CO_2 eq, respectively. Moreover, the optimal value of total cost shows a lower deviation at 0.2% above its target value. In contrast, the optimal value of global warming potential shows a higher deviation at 0.4% above its target value. This means the manufacturer satisfaction is dependent on how much of one objective they are prepared to give up in order to gain in another.

Although total cost may decrease when more global warming potential is generated, the quantity of raw material usage, as the consequence of the trade-off between these two objectives suggests is the best compromise solution, as is shown in Table 4. Among the five types of plastic resin in film blowing activity, plastic resin type B is found to be increased compared to its typical quantity. This is because it has lower cost and less greenhouse gas (GHG) emissions than the other types of plastic resin. In addition, although the cost of CMYK ink is higher than other solvents used in printing, it is found to increase as compared to its typical quantity because of the limitation in solvents usage. Due to lower GHG emissions there is an increase of adhesive component type B in laminating activity. As a result, the model output suggests that above raw materials should be increased in response to the trade-off relationship between the two objectives. On the other hand, the usage of other raw materials is decreased, subject to their constraints.

Table 3. Optimal values of two objective functions.

Objective function	**Weight importance factor**	**Unit**	**Optimal value**	**Maximum of weight percentage deviation from target values (Q)**
Minimized total cost	$w_1 = 1.0$	$US	$Z_1 = 6018.27$	0.0030
Minimized GWP	$w_2 = 1.0$	kg CO_2 eq	$Z_2 = 2789$	
Minimized total cost	$w_1 = 4.6$	$US	$Z_1 = 6012.23$	0.0091
Minimized GWP	$w_2 = 2.4$	kg CO_2 eq	$Z_2 = 2791$	

Table 4. Best compromise solution between two objective functions in case of $w_1 = 4.6$ and $w_2 = 2.4$.

Activity	**Raw material**	**Unit**	**Usage**	**Compare with typical quantity[a]**
Film blowing	Plastic resin type A	kg	198.00	Decrease
	Plastic resin type B	kg	270.00	Increase
	Plastic resin type C	kg	198.00	Decrease
	Plastic resin type D	kg	117.00	Decrease
	Plastic resin type E	kg	117.00	Decrease
Printing	Printing cylinder	Rolls	6.00	Constant
	CPP film	kg	132.00	Constant
	CMYK ink	kg	18.34	Increase
	Other ink	kg	0.47	Decrease
	Solvent type A	kg	1.88	Decrease
	Solvent type B	kg	1.88	Decrease
	Solvent type C	kg	0.94	Decrease
Laminating	Adhesive component A	kg	8.10	Decrease
	Adhesive component B	kg	27.10	Increase
	Solvent type C	kg	45.79	Decrease
Bag forming	Paper core	kg	19.29	Constant
	OPP tape	kg	0.03	Constant
Packing	PE film wrap	kg	1.63	Constant

[a] The typical quantity represents the quantity of raw material which incurred during the real production.

4. Discussion

As the best compromise solution, the optimal values of total cost and global warming potential are found to be $US 6012.23 and 2791 kg CO_2 eq, respectively. Therefore the sensitivity analysis of this MOLP model shows a slight improvement in the optimal value of total cost and global warming potential at 0.1% and 1.5% below their typical values that occur during actual production. However, the system boundary of the model and data availability also implies several limitations. For example, this study focuses on the main activity in the production line of CPP/LLDPE rice bag, but due to a limit of data availability, does not cover the production of CPP film. Likewise some of the data, including labor cost, transportation cost and emission factor is obtained from secondary data. The constraints of raw material usage can be adjusted according to the manufacturer preference.

Thus, there is an opportunity for further improvement in each objective for the minimization of total cost and lowering of global warming potential.

5. Conclusion

Integration of MOLP and LCA can be used to incorporate two aspects concerning economic and environmental issues. The model we developed is applied to determine the optimality of raw material usage for manufacturing the CPP/LLDPE rice bag as a consequence of the trade-off between two objective functions: minimized total cost and minimized global warming potential. According to the results gained from the MOLP model, the best solution shows a slight improvement in the optimal values of total cost and global warming potential at 0.1% and 1.5% respectively, below their typical values incurred in actual production. The compromise solution obtained can identify opportunities to affect production improvement. To this end, the developed model can be used as a decision-support tool to determine a compromise solution to both objectives based on the manufacturer preference and constraints. Also, the model can be used as model prototype for other flexible packaging systems for rice, such as Nylon/LLDPE and PET/LLDPE (polyethylene terephthalate/linear low density polyethylene) in the future.

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