A binary

by Feri Afrinaldi

A Binary Linear Programming Approach for LCA System Boundary Identification

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Abstract
One of the very first steps in conducting life cycle assessment (LCA) is system boundaries identification. A binary linear programming (LP) model is proposed to identify boundary between significant and insignificant processes in a LCA study. The proposed model is designed based on Relative Mass-Energy-Economic (RMEE) methodology. There are two types of objective function that can be solved by the proposed model, (1) to minimize number of processes considered in LCA or (2) to maximize cut-off criteria values. A numerical example and sensitivity analysis are provided to verify the applicability of the proposed model.

Keywords:
LCA; System Boundary; Linear Programming

1 INTRODUCTION

LCA is a tool used to assess environmental impact of a product. The assessment is conducted over life cycle of the product, from material extraction to end-of-life treatment. Figure 1 presents a general product life cycle [1].

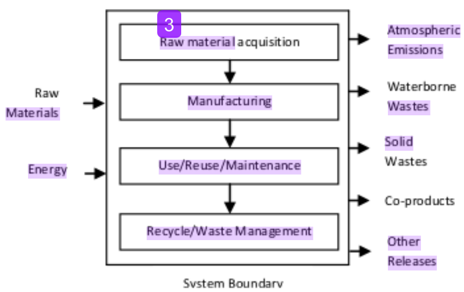

Figure 1: General Product Life Cycle [1].

As shown by Figure 1, box labeled as "system boundary" is a general system boundary of a LCA study. According to Tillman et al. [2] and Guinee et al. [3] there are 5 types of system boundary in LCA:

a) boundary between technical system and environment,
b) geographical area,
c) time horizon,
d) production of capital goods,
e) boundary between life cycle system of studied product and connected life-cycle systems of other products, and
f) boundary between significant and insignificant processes.

This paper concentrates on boundary between significant and insignificant processes. Defining boundary between significant and insignificant processes is not easy because when goals and scope are defined the significant and insignificant data are unknown [4].

2 EXISTING APPROACHES

Many LCA studies select system boundary qualitatively without a scientific basis. However, several methods have been proposed to guide practitioners in identifying LCA system boundary. For example, the use of percentage of mass to define system boundary can be found in Hunt et al. [5]. Criteria to stop are mass ratios. If ratio of mass used is 0.01, it means that if ratio of mass of an input to total mass of a process is less than 0.01 then this input is not considered in the system boundary. This approach is reasonable. However it does not quantify the significant of an input to the whole life cycle of a product.

Since data availability is also one of the difficulties in conducting LCA, the use of data availability in determining system boundary can be found in Mann et al. [6]. The weakness of this approach is that it has no scientific basis.

ISO standard [7] also provides guideline to identify LCA system boundary. It uses environmental significance as the criteria to select system boundary and requires impact assessment to be done before the system boundary is defined. This makes this methodology ineffective in practice.

Other approaches can be found in Raynolds et al. [8] and known as Relative Mass-Energy-Economic (RMEE) method. The following criteria are used by this method to cut system boundary [8].

$$M_{Ratio} = \frac{M_i}{M_{Total}} \quad (1)$$

$$E_{Ratio} = \frac{E_i}{E_{Total}} \quad (2)$$

$$E_{Ratio} = \frac{E_i}{E_{Total}} \quad (3)$$

$$\$_{Ratio} = \frac{\$_i}{\$_{Total}} \quad (4)$$

If $M_{Ratio} > Z_{RMEE}$ *then process* i *is inside system boundary, else outside system boundary.*

If $E_{Ratio} > Z_{RMEE}$ *then process* i *is inside system boundary, else outside system boundary.*

If $\$_{Ratio} > Z_{RMEE}$ *then process* i *is inside system boundary, else outside system boundary.*

Z_{RMEE} is boundary cut-off ratio ($0 < Z_{RMEE} < 1$). $M_i, E_i, \$_i$ are mass, energy and economic value of input i . $M_{Total}, E_{Total}, \$_{Total}$ are total mass, energy and economic value of the functional unit. Figure 2 shows RMEE procedure [8].

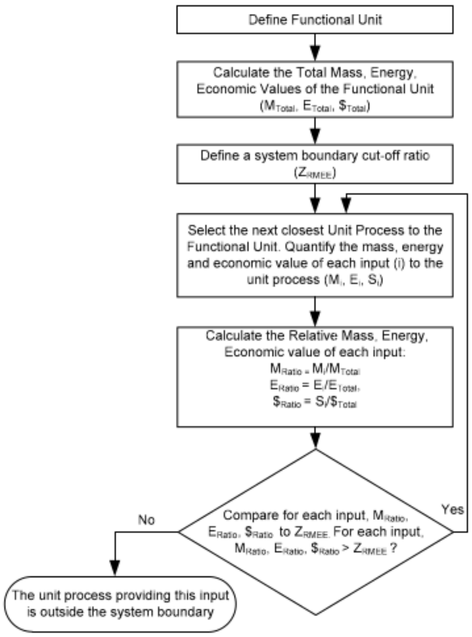

Figure 2: RMEE procedure [8].

RMEE method is quantitative, repeatable and streamlined. However this method does not incorporate data accessibility as one of the criteria to identify system boundary. Furthermore, RMEE also does not facilitate sensitivity analysis. If the cut-off ratio changes then the RMEE procedure has to be done all over again. Another question about RMEE is that how the value of the cut-off ratio is determined.

This paper formulates RMEE method as a binary LP model. In the proposed LP, the difficulties to collect inventory data are considered. Data collection cost is used to quantify those difficulties. In order to answer the question how cut-off ratio is defined, available budget to conduct LCA study is used as a constraint to determine how good cut-off ratio we can obtain. Moreover, since it is a mathematical programming approach then sensitivity analysis can be conducted easily.

3 BINARY LP MODEL TO IDENTIFY LCA SYSTEM BOUNDARY

3.1 Variables and Parameters

Let w, x, y, z be variables representing material extraction, manufacturing, use, and end-of-life phase respectively.

Suppose that w, x, y, z contain $i_1 = 1, 2, ..; j_1 = 1, 2, ..; k_1 = 1, 2, ...;$ and $l_1 = 1, 2, ...$ number of processes respectively and are denoted as $w_{i_1}, x_{j_1}, y_{k_1}$ and z_{l_1}. Similarly, suppose that $w_{i_1}, x_{j_1}, y_{k_1}$ and z_{l_1} have $i_2 = 1, 2, ... ; j_2 = 1, 2, ... ; k_2 = 1, 2, ...$ and $l_2 = 1, 2, ...$ number of processes respectively and are denoted as $w_{i_1 i_2}, x_{j_1 j_2}, y_{k_1 k_2}$ and $z_{l_1 l_2}$. Again, suppose that $w_{i_1 i_2}, x_{j_1 j_2}, y_{k_1 k_2}$ and $z_{l_1 l_2}$ contain $i_3 = 1, 2, ... ; j_3 = 1, 2, ..., k_3 = 1, 2, ...$ and $l_3 = 1, 2, ...$ number of processes respectively and are denoted as $w_{i_1 i_2 i_3}, x_{j_1 j_2 j_3}, y_{k_1 k_2 k_3}$ and $z_{l_1 l_2 l_3}$

Of course the number of variables can grow indefinitely, for simplification, let's say that they grow up to $i_n = 1, 2, .. ; j_n = 1, 2, . . . ; k_n = 1, 2, ...$ and $l_n = 1, 2, ...$ so that the last processes are denoted as $w_{i_1 i_2 i_3 \dots i_n}, x_{j_1 j_2 j_3 \dots j_n}, y_{k_1 k_2 k_3 \dots k_n}$ and $, z_{l_1 l_2 l_3 \dots l_n}$.The grow of those variables can be represented as a tree, shown by Figure 3.

All variables are binary (can only have a value of 0 or 1). If the value of a variable is 0 then the process represented by that variable is not inside system boundary, otherwise, if its value is 1 then the process represented by that variable is inside system boundary. Therefore, it can be expressed as, $w_{i_1}, x_{j_1}, y_{k_1}, z_{l_1}$; $w_{i_1 i_2}, x_{j_1 j_2}, y_{k_1 k_2}, z_{l_1 l_2}$; $w_{i_1 i_2 i_3}, x_{j_1 j_2 j_3}, y_{k_1 k_2 k_3}, z_{l_1 l_2 l_3}$; $w_{i_1 i_2 i_3 \dots i_n}, x_{j_1 j_2 j_3 \dots j_n}, y_{k_1 k_2 k_3 \dots k_n}, z_{l_1 l_2 l_3 \dots l_n} \in \{0, 1\}$. Furthermore, w, x, y and z are equal to 1 because they are the main life cycle stages and have to be included in the system.

Suppose that mass inputs for material extraction, manufacturing, use and waste treatment are $\alpha^w, \alpha^x, \alpha^y$ and α^z; energy inputs for material extraction, manufacturing, use and waste treatment are $\beta^w, \beta^x, \beta^y$ and β^z; the economic values of processes in material extraction, manufacturing, use and waste treatment are $\gamma^w, \gamma^x, \alpha^y$ and γ^z ; and inventory data collection costs are $\delta^w, \delta^x, \delta^y$ and δ^z.

Therefore, for example, parameters for w_{i_1} are $\alpha^w_{i_1}, \beta^w_{i_1}, \gamma^w_{i_1}$ and $\delta^w_{i_1}$ and parameters for $w_{i_1 i_2 i_3}$ are $\alpha^w_{i_1 i_2 i_3}, \beta^w_{i_1 i_2 i_3}, \gamma^w_{i_1 i_2 i_3}$ and $\delta^w_{i_1 i_2 i_3}$. All parameters must be defined per functional unit of the studied system.

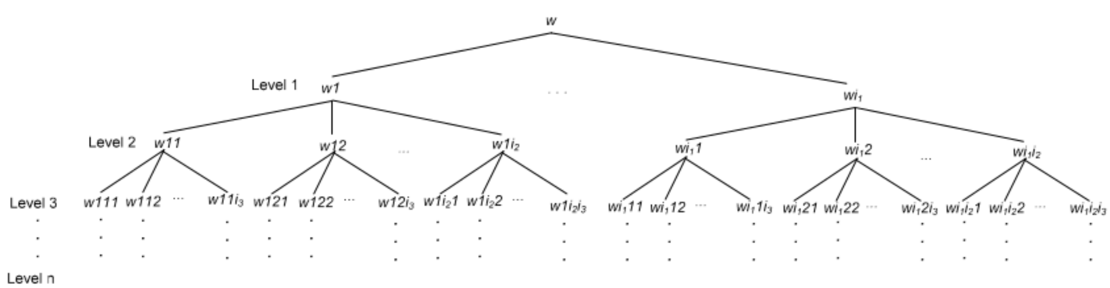

Figure 3: Variables or process tree for material extraction (*w*).

It is also defined that M_c, E_c, C_c are the cut-off criteria for material input, energy input and economic value, where $0 < M_c < 1, 0 < E_c < 1$ and $0 < C_c < 1$. If $M_c = 0.95$, it means that the ratio of sum of mass in the system boundary to total mass flowing in the system is 95%. The same meaning is also applicable for E_c and C_c. The closer those values to 1 the better the cut-off criteria. Finally B is total budget available to conduct a LCA study.

In the following section, objective functions and constraints are defined. For the purpose of simplification and because of limited space, variables included in the model are only up to level 3 (with 3 subscripts).

3.2 Objective Functions

There are two types of objective functions that can be selected, to minimize the number of processes considered in the LCA or to maximize cut-off criteria values. Equation (5) is the objective function formula for number of processes minimization and equation (6) is the objective function formula for cut-off criteria maximization.

$$Min\, Z = \sum_{i_1=1}^{m_1} w_{i_1} + \sum_{i_1=1}^{m_1}\sum_{i_2=1}^{m_2} w_{i_1 i_2} + \sum_{i_1=1}^{m_1}\sum_{i_2=1}^{m_2}\sum_{i_3=1}^{m_3} w_{i_1 i_2 i_3} + \sum_{i_1=1}^{n_1} x_{j_1} + \sum_{j_1=1}^{n_1}\sum_{j_2=1}^{n_2} x_{j_1 j_2} + \sum_{j_1=1}^{n_1}\sum_{j_2=1}^{n_2}\sum_{j_3=1}^{n_3} x_{j_1 j_2 j_3} + \sum_{k_1=1}^{0_1} y_{1_1} + \sum_{k_1=1}^{o_1}\sum_{k_2=1}^{0_2} y_{i_1 i_2} + \sum_{k_1=1}^{0_1}\sum_{k_2=1}^{0_2}\sum_{k_3=1}^{0_3} y_{k_1 k_2 k_3} + \sum_{l_1=1}^{p_1} z_{l_1} + \sum_{l_1=1}^{p_1}\sum_{l_2=1}^{p_2} z_{l_1 l_2} + \sum_{l_1=1}^{p_1}\sum_{l_2=1}^{p_2}\sum_{l_3=1}^{p_3} z_{l_1 l_2 l_3} \quad (5)$$

$$Max\, Z = \frac{1}{3}(M_c + E_c + C_c) \quad (6)$$

Where,

$$M_c = \frac{1}{\alpha_{Total}}\left(\sum_{i_1=1}^{m_1} \alpha_{i_1}^{w} w_{i_1} + \cdots + \sum_{l_1=1}^{p_1}\sum_{l_2=1}^{p_2}\sum_{l_3=1}^{p_3} \alpha_{l_1 l_2 l_3}^{z} z_{l_1 l_2 l_3}\right) \quad (7)$$

$$E_c = \frac{1}{\beta_{Total}}\left(\sum_{i_1=1}^{m_1} \beta_{i_1}^{w} w_{i_1} + \cdots + \sum_{l_1=1}^{p_1}\sum_{l_2=1}^{p_2}\sum_{l_3=1}^{p_3} \beta_{l_1 l_2 l_3}^{z} z_{l_1 l_2 l_3}\right) \quad (8)$$

$$C_c = \frac{1}{\gamma_{Total}}\left(\sum_{i_1=1}^{m_1} \gamma_{i_1}^{w} w_{i_1} + \cdots + \sum_{l_1=1}^{p_1}\sum_{l_2=1}^{p_2}\sum_{l_3=1}^{p_3} \gamma_{l_1 l_2 l_3}^{z} z_{l_1 l_2 l_3}\right) \quad (9)$$

$\alpha_{Total}, \beta_{Total}$ and γ_{Total} are total mass input, energy input and economic value in the studied system.

3.3 Constraints

If the selected objective function is equation (5) then the constraints are the following.

$$\sum_{i_1=1}^{m_1} w_{i_1} \le Mw \quad (10)$$

$$\sum_{i_2=1}^{m_2} w_{i_1 i_2} \le Mw_{i_1},\ \forall\, i_1 \quad (11)$$

$$\sum_{i_3=1}^{m_3} w_{i_1 i_2 i_3} \le Mw_{i_1 i_2}, \forall\, i_1 i_2 \quad (12)$$

$$\sum_{i_1=1}^{n_1} x_{j_1} \le Mx \quad (13)$$

$$\sum_{j_2=1}^{n_2} x_{j_1 j_2} \le Mx_{j_1},\ \forall\, j_1 \quad (14)$$

$$\sum_{j_3=1}^{n_3} x_{j_1 j_2 j_3} \le Mx_{j_1 j_2},\ \forall\, j_1 j_2 \quad (15)$$

$$\sum_{k_1=1}^{o_1} y_{k_1} \le My \quad (16)$$

$$\sum_{k_2=1}^{o_2} y_{k_1 k_2} \le My_{k_1},\ \forall\, k_1 \quad (17)$$

$$\sum_{k_3=1}^{o_3} y_{k_1 k_2 k_3} \le My_{k_1 k_2},\ \forall\, k_1 k_2 \quad (18)$$

$$\sum_{l_1=1}^{p_1} z_{l_1} \le Mz \quad (19)$$

$$\sum_{l_2=1}^{p_2} z_{l_1 l_2} \le Mz_{l_1},\ \forall\, l_1 \quad (20)$$

$$\sum_{l_3=1}^{p_3} z_{l_1 l_2 l_3} \le Mz_{l_1 l_2}, \forall\, l_1 l_2 \quad (21)$$

$$\frac{1}{\alpha_{Total}}\left(\sum_{i_1=1}^{m_1} \alpha_{i_1}^{w} w_{i_1} + \cdots + \sum_{l_1=1}^{p_1}\sum_{l_2=1}^{p_2}\sum_{l_3=1}^{p_3} \alpha_{l_1 l_2 l_3}^{z} z_{l_1 l_2 l_3}\right) \ge M_c \quad (22)$$

$$\frac{1}{\beta_{Total}}\left(\sum_{i_1=1}^{m_1} \beta_{i_1}^{w} w_{i_1} + \cdots + \sum_{l_1=1}^{p_1}\sum_{l_2=1}^{p_2}\sum_{l_3=1}^{p_3} \beta_{l_1 l_2 l_3}^{z} z_{l_1 l_2 l_3}\right) \ge E_c \quad (23)$$

$$\frac{1}{\gamma_{Total}}\left(\sum_{i_1=1}^{m_1} \gamma_{i_1}^{w} w_{i_1} + \cdots + \sum_{l_1=1}^{p_1}\sum_{l_2=1}^{p_2}\sum_{l_3=1}^{p_3} \gamma_{l_1 l_2 l_3}^{z} z_{l_1 l_2 l_3}\right) \ge C_c \quad (24)$$

$$\sum_{i_1=1}^{m_1} \delta_{i_1}^{w} w_{i_1} + \cdots + \sum_{l_1=1}^{p_1}\sum_{l_2=1}^{p_2}\sum_{l_3=1}^{p_3} \delta_{l_1 l_2 l_3}^{z} z_{l_1 l_2 l_3} \le B \quad (25)$$

$$w_{i_1}, w_{i_1 i_2}, w_{i_1 i_2 i_3}, x_{i_1}, x_{i_1 i_2}, x_{i_1 i_2 i_3}, y_{i_1}, y_{i_1 i_2}, y_{i_1 i_2 i_3}, z_{i_1}, z_{i_1 i_2}, z_{i_1 i_2 i_3} \epsilon \{0, 1\} \quad (26)$$

Inequalities (10) until (21) are linking constraints which mean that values of some variables depend on value of a certain variable. For example, suppose that process w_{11} and w_{12} are selected then process w_1 has to be selected because process w_{11} and w_{12} are inside process w_1. The number M represents an upper bound of any sum of the variables in the model. In other words M is at least as large as any sum of the variables we can feasibly get. Inequalities (22), (23) and (24) are constraints for cut-off criteria. Inequality (25) is budget constraint and (26) is binary constraint. If the selected objective function is equation (6) then the constraints are formulas (10), (11), (12), (13), (14), (15), (16), (17), (18), (19), (20), (21) and (26).

4 NUMERICAL EXAMPLE

Suppose that we want to do LCA study for the system represented by Figure 4. Mass, energy, and cost to collect inventory data is given by Table 1. Mass and energy values given are per functional unit. Information regarding economic values of a process is not given therefore it is not considered. Our objective is to identify system boundary and maximize overall cut-off criteria. Budget available to conduct LCA study is 400. Note that this example is not a real case study. The purpose of the example is just to demonstrate and verify the model.

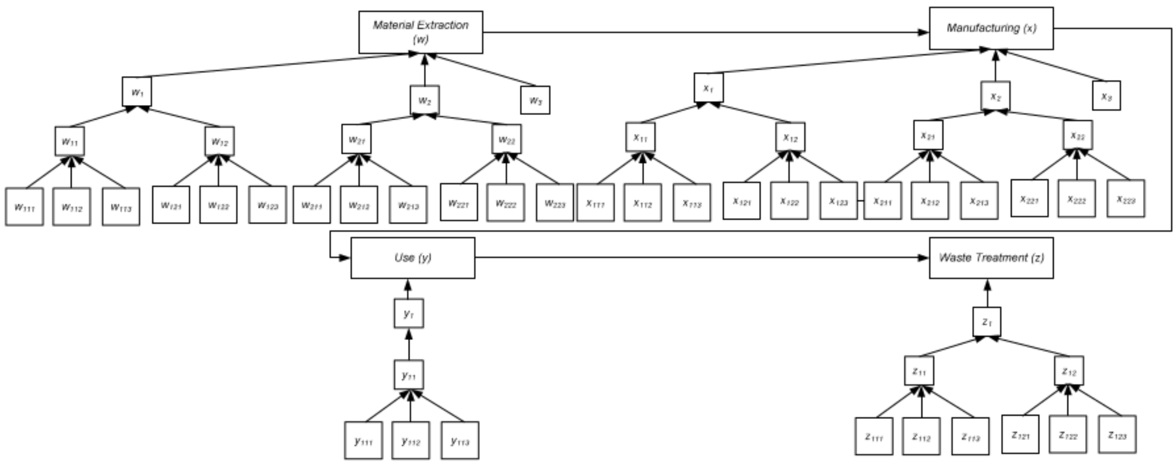

Figure 4: System for the numerical example.

Life cycle stage	***Process (Level 1)***	***Mass***	***Energy***	***Cost***	***Process (Level 2)***	***Mass***	***Energy***	***Cost***	***Process (Level 3)***	***Mass***	***Energy***	***Cost***
w	w_1	*2*	*91*	*1*	w_{11}	*6*	*27*	*19*	w_{111}	*10*	*92*	*15*
									w_{112}	*10*	*28*	*15*
									w_{113}	*0*	*50*	*3*
					w_{12}	*7*	*79*	*11*	w_{121}	*1*	*93*	*6*
									w_{122}	*2*	*91*	*9*
									w_{123}	*1*	*45*	*15*
	w_2	*3*	*79*	*12*	w_{21}	*8*	*7*	*2*	w_{211}	*1*	*20*	*15*
									w_{212}	*8*	*58*	*4*
									w_{213}	*8*	*88*	*17*
					w_{22}	*5*	*98*	*16*	w_{221}	*1*	*18*	*12*
									w_{222}	*3*	*77*	*12*
									w_{223}	*0*	*65*	*6*
	w_3	*9*	*5*	*4*								
x	x_1	*8*	*27*	*10*	x_{11}	*2*	*19*	*4*	x_{111}	*3*	*96*	*3*
									x_{112}	*9*	*49*	*20*
									x_{113}	*7*	*33*	*1*
					x_{12}	*6*	*99*	*14*	x_{121}	*5*	*36*	*5*
									x_{122}	*0*	*77*	*2*
									x_{123}	*9*	*59*	*4*
	x_2	*1*	*20*	*0*	x_{21}	*7*	*85*	*8*	x_{211}	*6*	*70*	*10*
									x_{212}	*10*	*94*	*8*
									x_{213}	*3*	*15*	*7*
					x_{22}	*5*	*58*	*8*	x_{221}	*0*	*15*	*8*
									x_{222}	*10*	*75*	*9*
									x_{223}	*7*	*76*	*9*
	x_3	*5*	*64*	*19*								

Table 1: Data.

Life cycle stage	*Process (Level 1)*	*Mass*	*Energy*	*Cost*	*Process (Level 2)*	*Mass*	*Energy*	*Cost*	*Process (Level 3)*	*Mass*	*Energy*	*Cost*
y	y_1	2	2	20	y_{11}	9	5	13	y_{111}	4	68	15
									y_{112}	1	48	17
									y_{113}	2	15	13
z	z_1	3	13	2	z_{11}	2	69	20	z_{111}	2	52	7
									z_{112}	9	83	20
									z_{113}	5	70	4
					z_{12}	5	53	17	z_{121}	6	26	18
									z_{122}	1	78	6
									z_{123}	9	79	1

Table 1: Data (*continued*).

The binary linear programming model is the following.

$$Max\ Z = \frac{1}{2}\,(M_c + E_c)$$

where,

$$M_c = \frac{\begin{array}{c} 2w_1 + 3w_2 + 9w_3 + 8x_1 + x_2 + 5x_3 + 2y_1 + 3z_1 + 6w_{11} + \cdots + \\ 2x_{11} + \cdots + 9y_{11} + \cdots + 2z_{11} + \cdots + 10w_{111} + \cdots + 9z_{123} \end{array}}{\begin{array}{c} 2+3+9+8+1+5+2+3+6+\cdots+ \\ 2+\cdots+9+\cdots+2+\cdots+10+\cdots+9 \end{array}}$$

$$E_c = \frac{\begin{array}{c} 91w_1 + 79w_2 + 5w_3 + 27x_1 + 20x_2 + 64x_3 + 2y_1 + 13z_1 + 27w_{11} \\ + \cdots + 19x_{11} + \cdots + 5y_{11} + \cdots + 69z_{11} + \cdots + 92w_{111} + \cdots + 79z_{123} \end{array}}{\begin{array}{c} 91+79+5+27+20+64+2+13+27 \\ +\cdots+2+\cdots+9+\cdots+2+\cdots+10+\cdots+9 \end{array}}$$

Subject to,

$w_1 + w_2 + w_3 \le Mw$

$x_1 + x_2 + x_3 \le Mx$

$y_1 \le My$

$z_1 \le Mz$

$w_{11} + w_{12} \le Mw_1$

$w_{21} + w_{22} \le Mw_2$

$x_{11} + x_{12} \le Mx_1$

$x_{21} + x_{22} \le Mx_2$

$y_{11} \le My_1$

$z_{11} + z_{12} \le Mz_1$

$w_{111} + w_{112} + w_{113} \le Mw_{11}$

$w_{121} + w_{122} + w_{123} \le Mw_{12}$

$w_{211} + w_{212} + w_{213} \le Mw_{21}$

$w_{221} + w_{222} + w_{223} \le Mw_{22}$

$x_{111} + x_{112} + x_{113} \le Mx_{11}$

$x_{121} + x_{122} + x_{123} \le Mx_{12}$

$x_{211} + x_{212} + x_{213} \le Mx_{21}$

$x_{221} + x_{222} + x_{223} \le Mx_{22}$

$y_{111} + y_{112} + y_{113} \le My_{11}$

$z_{111} + z_{112} + z_{113} \le Mz_{11}$

$z_{121} + z_{122} + z_{123} \le Mz_{12}$

$$\begin{pmatrix} w_1 + 12w_2 + 4w_3 + 10x_1 + 0x_2 + 5x_3 + 20y_1 + 2z_1 + 19w_{11} \\ + \cdots + 14x_{11} + \cdots + 13y_{11} + \cdots + 2z_{11} + \cdots + 15w_{111} + \cdots + 1z_{123} \end{pmatrix} \le 400$$

$w_1, w_2, w_3, x_1, x_2, x_3, y_1, z_1, w_{11}, \cdots, x_{11}, \cdots, y_{11}, \cdots, z_{11}, \cdots, w_{111}, \cdots, z_{123} \in \{0, 1\}$

The solutions of this simple problem are the following.

$w = x = y = 1$ because they are the main life cycle stages.

$w_1 = w_2 = w_3 = 1,$

$x_1 = x_2 = 1, x_3 = 0,$

$y_1 = 1, z_1 = 1,$

$w_{11} = w_{12} = w_{21} = w_{22} = 1$

$x_{11} = x_{12} = x_{21} = x_{22} = 1$

$y_{11} = 1,$

$z_{11} = z_{12} = 1,$

$w_{111} = w_{112} = w_{113} = 1,$

$w_{121} = w_{122} = 1, w_{123} = 0,$

$w_{211} = 0, w_{212} = w_{213} = 1,$

$w_{221} = 0, w_{222} = w_{223} = 1,$

$x_{111} = x_{112} = x_{113} = 1,$

$x_{121} = x_{122} = x_{123} = 1,$

$x_{211} = x_{212} = x_{213} = 1,$

$x_{221} = 0, x_{222} = x_{223} = 1,$

$y_{111} = 1, y_{112} = y_{113} = 0,$

$z_{111} = z_{112} = z_{113} = 1,$

$z_{121} = 0, z_{122} = z_{123} = 1.$

$$Z = \frac{1}{2}\,(M_c + E_c) = \frac{1}{2}\,(0.93 + 0.91) = 0.92.$$

Total budget spent is 400 and the selected boundary is shown by Figure 5.

Suppose that we vary the budget from 375 to 575. The change in objective function value with respect to budget change is given by Figure 6 that shows when the budget reaches 535 it is possible to consider all processes in the system.

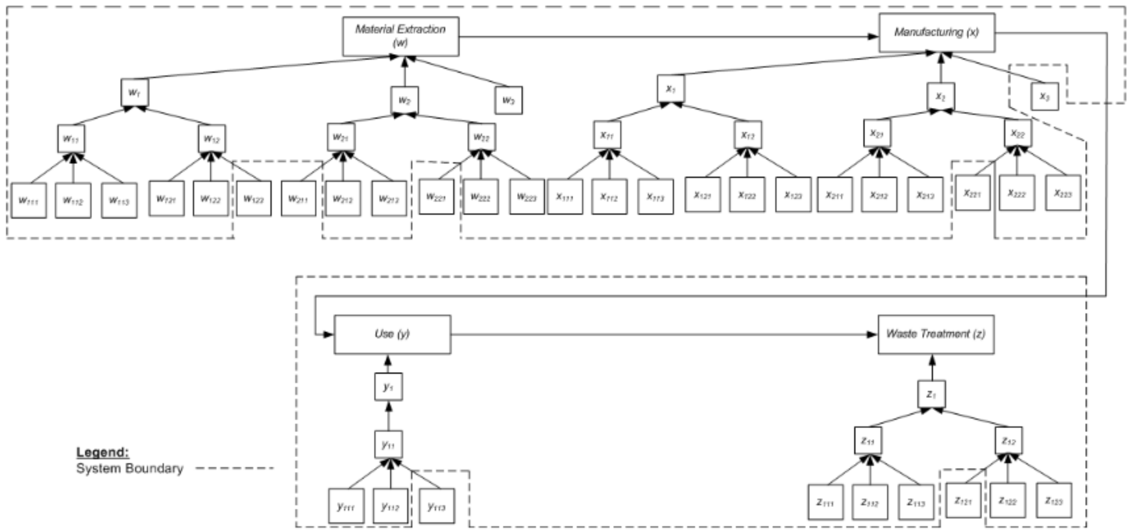

Figure 5: Selected system boundary.

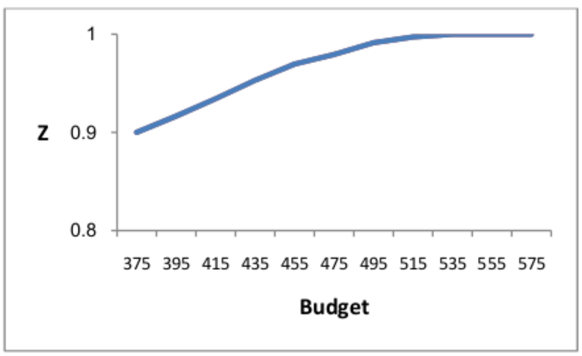

Figure 6: Change in objective function value with respect to budget change.

5 CONCLUSION

A binary linear programming approach to select system boundary of a LCA study is proposed. The proposed method is based on RMEE methodology presented in Raynolds et al. [8]. The main differences between the proposed methodology and RMEE are (1) RMEE is a repetitive approach; our approach is an optimization approach, (2) in our approach cut-off ratios are determined based on data accessibility (cost to collect inventory data); in RMEE the cut-off ratio is given, and (3) since our approach is a mathematical programming model therefore sensitivity analysis is easy to be done.

In the future, it is expected that computer software will be developed based on this methodology so that practitioners can easily determine their LCA boundary based on their available budget, mass flow, energy flow and economic values of the processes.

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