An Integer Programming Model for Alternative Selection and Planning Stages for Cleaner Production Programs: a Case Study for Greenhouse Gases Reduction

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ABSTRACT

The selection of subjects (such as waste stream, process, apparatus, ect.) for improvement and development their alternatives when implementing cleaner production (CP) programs at the company in order to achieve the highest efficiency is a complex and time-consuming process, especially in case when there are many subjects to be improved, and many alternatives for each subject. The problem in this case is which subject and its respective alternative is to be selected in order to obtain maximal waste reduction objective with minimization cost. To solve this problem, this article proposes an optimization mathematical model to support alternatives selection for CP programs. In this study, an integer programming model is applied for defining theselection steps of alternatives and setting the implementing plan within CP program. The proposed model is investigated in a real case study at a cassava starch factory in Tay Ninh, Vietnam (where is the most concentrated area of cassava processing in the country) with purpose to propose the measures for reduction of greenhouse gases (GHGs) and electricity consumption. The results show that this model can be considered as a new effective method for alternative CP selection and planning for CP implementation, especially in case of many subjects and alternatives. The solution of this model can be generalized to apply in any cases with unlimited number of subjects and alternatives.

Keywords: Goal Programming, Cleaner Production, Industrial Pollution Prevention, Cassava Starch Processing, Decision Support System

1. INTRODUCTION

The successful CP programs provide many benefits including operating costs reduction, raw material use reduction, waste reduction and risk reduction to humans and the environment, improving health and occupational safety, adaptation to environmental protection regulations. Cagno, Trucco [1] analyzed 134 pollution prevention projects and found that savings 31% of production cost, 33% of waste and 6% of raw materials. In Vietnam, the

companies interested in cleaner production program increase significantly, and the results achieved from implementation of cleaner production programs become more and more obvious. Just for an example of electricity savings potential: in textile industry is 3-57%, in paper industry is 3-25%, and in the beer industry is 40-60% [2]. However, the successful implementation of CP program is not really high because of many barriers. Luken [3] when studying on the implemented CP projects, indicated that the awareness of CP was improved, however, the CP concept had not been known or fully understood by all industrial and service sectors. A more important barrier is the discrepancy between people trained as assessors and the number of assessors who are qualified and experienced enough to actually conduct in-plant assessments[3]. Another aspect that may contribute to these problems is that traditional CP only focuses in solutions with attractive financial indices (high IRR, short payback period), while not all CP solutions are economically feasible, and some solutions only reduce pollution and bring other benefits (eg improved company image, or achievement of reduction objective is required by the third party).

Shi, Peng [4] pointed out that for the small and medium enterprises, the top three barriers are lack of economic incentive policies, lack of environmental enforcement, and high initial capital cost. There are also other important barriers such as lack of effective CP assessment (CPA) measures, and the lack of financial service institutions [4], or no knowledge on CPA and CP, poor accounting and internal auditing systems within companies [5], difficult to quantify all the benefits of cleaner production measures [3]. In addition, Cagno, Trucco [1] inferred that the scarce use of systematic techniques and tools that adopted by companies was still in the early stage and was not completely integrated into the management process.

In general, technical barriers are often found in the literature and are cited as a significant barrier to sustainable CP initiatives. In order to lessen the impact of technique obstacles in the uptake of CP, quality tools [6] and LCA indicators are suggested as tools for CP [7]. Therefore, it can be expected that some benefits of a CP program will be maximized. Silva, Delai [6]The successful CP programs provide many benefits including operating costs reduction, raw material use reduction, waste reduction and risk reduction to humans and the environment, improving health and occupational safety, adaptation to environmental protection regulations. Cagno, Trucco [1] analyzed 134 pollution prevention projects and found that savings 31% of production cost, 33% of waste and 6% of raw materials. In Vietnam, the companies interested in cleaner production program increase significantly, and the results achieved from implementation of cleaner production programs become more and more obvious. Just for an example of electricity savings potential: in textile industry is 3-57%, in paper industry is 3-25%, and in the beer industry is 40-60% [2]. However, the successfulSilva, Delai [6] after reviewing common barriers of CP programs, proposing a new CP methodology enhanced by a systematic integration of quality tools that helps to overcome the aforementioned problems. The use of these tools can enhance nearly all steps of a CP methodology, namely the planning stage, crucial for the success a CP program. For alternative selection and planning phases in implementation cleaner production programs, Silva, Delai [6] propose to use GUT matrix and 5W2H tools. These tools have the advantage of being easy to use but difficult to apply to multi-subjects and each subject has many alternatives. Another limitation of these tools is not considering waste reduction objectives and the budget for innovation to provide the optimal options.
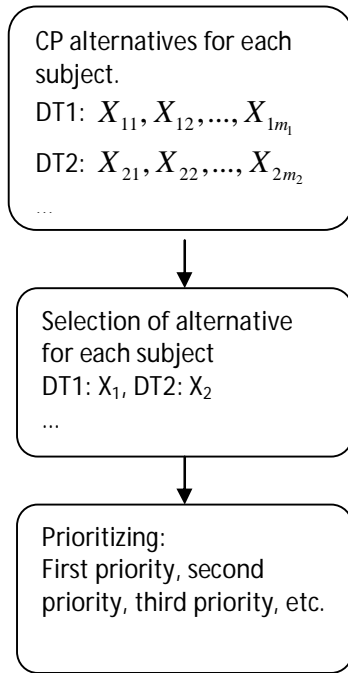
While, goal programming (GP) is a multi-criteria decision making technique, it is traditionally seen as an extension of linear programming to include multiple objectives, expressed by means of the attempted achievement of goal target values for each objective. Goal programming are widely applied in many fields, and normally divided into 16 main groups (such as academic management, agricultural management, energy planning and production, engineering, environmental and waste management ... [8]. Initially, a review conducted on electronic databases shows that 50,400 results with keywords 'goal programming', 1780 results with "goal programming" plus "waste management" and 117 results with "goal programming" plus "waste management" plus "environment management" are obtained in the initial search. None of these articles present a goal programming methodology for implementation of a cleaner production program. Some typical articles related to environmental and waste management field can be found in Chang and Hwang [9], Chakraborty and Linninger [10], Costi, Minciardi [11], Mavrotas [12] and Ghobadi, Darestani [13]. In particular, Mavrotas [12] suggested a GP model for pollution reduction in order to define Best Available Techniques -BAT necessary for typical industrial sectors in Athens, Greece. For municipal waste management, a research of Costi, Minciardi [11] proposed a GP model to support the decision makers in planning and selection of waste treatment measures which satisfied the requirement of environmentally-friendly criterions. Chang and Hwang [9] recommended an optimal model for waste minimization, optimal cost in selecting the heating system at the chemical factory. Chakraborty and Linninger [10] proposed the design method of waste treatment systemfollowing the GP method in which the model offered suitable technical options for each waste type and satisfied with given targets. While Ghobadi, Darestani [13] developed general MILP model for minimization the impact of greenhouse gases.

In generally, GP is an effective decision support tool for alternative selection. In this context, this paper proposes an optimization mathematical model based on goal programming into cleaner production methodology for selecting alternatives with objective to reach pollution reduction goal and to satisfy with available financial sources of the company.

2. PROBLEM DEFINITION

In general, the CP program comprises of six steps [14] in which step 2, 3 and 4 select CP options for further implementation, and eliminate the infeasible options in the technical, environmental and economic aspects. The CP assessment practice indicates that for each object which need to be improved, the CP team applies the methods such as brainstorming and benchmarking to identify alternatives (at least two), then analyzes to choose the best for further implementation (to improve this subject). After selecting the improved alternatives for each subject the CP team then develops an implementation plan by prioritizing the CP options on the basis of multi-criteria method [6, 14]. The selection process of CP alternatives at a traditional CP program is shown in figure 1. Under this approach, the option with highest priority will be implemented first, then the second, the third etc [6]. This approach has the advantage of being easy to assess, however, the decision factors such as reduction targets and resources (usually budget for mitigation) are not involved in the analysis and selection of alternatives. Therefore, the group of selected alternatives from independent selection may not be an optimal choice for the company.

CP alternatives for each subject.
DT1: $X_{11}, X_{12}, ..., X_{1m_1}$
DT2: $X_{21}, X_{22}, ..., X_{2m_2}$
...

Selection of alternative for each subject
DT1: X$_1$, DT2: X$_2$
...

Prioritizing:
First priority, second priority, third priority, etc.

Figure 1. The selection CP alternatives of a traditional CP program

To cope with this challenge in the concerned problem, after the CP team identifies the subjects that need to be improved (n subjects), the CP team continues developing various CP alternatives - X$_{ij}$ for each subject (where: m$_i$ number of alternatives for subject i, j= 1..m$_i$, i=1..n). Then, CP team collected information to calculate investment costs - C$_{ij}$ and emissions - E$_{ij}$ of each alternative. After that, CP team analyses the feasibility of each option then only rejected alternatives that technical or environmental infeasibility. Innovation subjects and their alternatives are shown as table 1.

The main issues to be addressed in CP alternative selection of CP programs under multi subject and multi alternative conditions, includes determining the numbers and alternatives of subjects with respect to two cases: 1- minimization of total cost and adaptation to waste reduction objective; 2 - maximization of waste reduction and adaptation to the budget for innovation.

Table 1. Innovation subjects and their alternatives in general

Quantity	Subject need innovation	CP alternatives		
		Alternative code	Investment cost	Emission
q$_1$	DT$_1$	$X_{11}, X_{12}, ..., X_{1m_1}$	$C_{11}, C_{12}, ..., C_{1m_1}$	$E_{11}, E_{12}, ..., E_{1m_1}$
q$_2$	DT$_2$	$X_{21}, X_{22}, ..., X_{2m_2}$	$C_{21}, C_{22}, ..., C_{2m_2}$	$E_{21}, E_{22}, ..., E_{2m_2}$
...	....	......		
q$_i$	DT$_i$	$X_{i1}, X_{i2}, ..., X_{im_j}$	$C_{i1}, C_{i2}, ..., C_{im_j}$	$E_{i1}, E_{i2}, ..., E_{im_j}$
...	...	....		
q$_n$	DT$_n$	$X_{n1}, X_{n2}, ..., X_{nm_n}$	$C_{n1}, C_{n2}, ..., C_{nm_n}$	$E_{n1}, E_{n2}, ..., E_{nm_n}$

3. MODEL FORMULATION

The indices, parameters and variables used to formulate the concerned CP alternative selection problem are described below.

- DT$_i$: group of similar subjects for innovation i: i= 1…n

- q$_i$: number of similar subjects of DT$_i$

- m$_i$: number of alternatives of subject DT$_i$

- X$_{ij}$: CP alternatives of DT$_i$, j=1…m$_i$

- X$_{i0}$: baseline of DT$_i$ (without innovation)

- C$_{ij}$: investment cost of X$_{ij}$

- E$_{ij}$: emission of X$_{ij}$

- b_{ij} : number of subjects of DT_i improved by X_{ij}
- Z_{max}: maximization of emission reduction potential
- Z: emission reduction potential
- C: total cost
- C_0: budget for emission reduction
- Z_0: emission reduction objective

3.1 Objective Functions

As mentioned in the section 2, there are two cases of CP alternative selection of CP programs under multi subject and multi alternative conditions: case 1- minimization of total cost and adaptation to GHG reduction objective; case 2- maximization of GHG reduction and adaptation to the budget for innovation.

Objective function of case 1:

Total investment cost of subjects of DT_i improved by X_{ij} = number of subjects of DT_i improved by X_{ij} x investment cost of X_{ij}. Thus, the objective function of case 1 can be written as follows.

$$MinC = \sum_{j=1}^{m_1} C_{1j}b_{1j} + ... + \sum_{j=1}^{m_i} C_{ij}b_{ij} + ... + \sum_{j=1}^{m_n} C_{nj}b_{nj}$$

Objective function of case 2:

GHG reduction potential of subjects of DT_i improved by X_{ij} = number of subjects of DT_i improved by X_{ij} x (baseline emission of DT_i - emission of X_{ij}). Therefore, the objective function of case 2 can be written as follows.

$$MaxZ = \sum_{i=1}^{n} E_{i0}(\sum_{j=1}^{m_i} b_{ij}) - (\sum_{j=1}^{m_1} E_{1j}b_{1j} + ... + \sum_{j=1}^{m_i} E_{ij}b_{ij} + ... + \sum_{j=1}^{m_i} E_{nj}b_{nj})$$

3.2 Constraints

Constraint of case 1:

The objective of waste reduction is Z_o. Thus, total GHG reduction potential is not less than Z_o.

Constraint of GHG reduction potential can be formulated as follows.

$$Z_0 \le \sum_{i=1}^{n}(E_{i0}\sum_{j=1}^{m_i} b_{ij}) - (\sum_{j=1}^{m_1} E_{1j}b_{1j} + ... + \sum_{j=1}^{m_i} E_{ij}b_{ij} + ... + \sum_{j=1}^{m_i} E_{nj}b_{nj})$$

Constraint of case 2:

The budget of waste reduction is C_o. Thus, total investment cost must be less than C_o. Constraint of investment cost can be formulated as follows.

$$C_0 \ge \sum_{j=1}^{m_1} C_{1j}b_{1j} + ... + \sum_{j=1}^{m_i} C_{ij}b_{ij} + ... + \sum_{j=1}^{m_n} C_{nj}b_{nj}$$

3.3. Decision Variables Constraints

b_{ij} is the non-negative integer variable. The total number of the selected alternatives of each group (DT_i) does not exceed the number of subjects of DT_i. The following constraints are related to these restrictions on the decision variables.

$$b_{ij} \in Z^+$$

$$0 \le \sum_{j=1}^{m_i} b_{ij} \le q_i$$

In case of q_i is 1 for any i so that $b_{ij} = \{0, 1\}$. Thus, the proposed model can be called the binary programming model (a particular case of integer programming).

4. CASE STUDY

Case study description

In this section, the validity of the developed CP alternative selection model under multi-subject and multi-alternative conditions is investigated via the data withdrawn from the considered case study. The cassava starch manufacturer firm A (Huu Duc's cassava starch

production factory) located in Tay Ninh province, Vietnam is a starch factory with 70 tons of starch per day. This firm is a modern cassava starch factory, the cassava starch production process begins with washing of harvested roots, rasping of washed roots by the rasper, extracting by a series of extractors, concentrating the slurry by separators, dewatering the slurry by a centrifuge and dryingthe starch cake by a flash dryer. At this production capacity, around 350 ton fresh roots are consumed; the conversion ratio of root and starch is therefore around from 5: 1. The water consumption of starch production is estimated to be 12 m^3 per ton starch and electricity consumption is 200 kWh per ton starch (equivalent to 720 MJ per ton of starch).

However, the average electricity consumption in Vietnam is about 608 MJ per ton starch production [15]. In Thai cassava starch production, electricity consumption is from 320 to 929MJ per ton starch [16]. Literature review shows that firm A is higher electricity consumption per ton starch than average consumption of other studies. The reasons may come from a poor control on technology process (there are no proper quality and environmental management systems following the international standards) and the backward technology when comparing with Thailand technology. Most of motors/apparatuses of the firm are made in Vietnam, there are likely not comprehensive and are practically innovated from the handicraft technology, therefore, one of the main reasons of the firm A is standard electric motor system use. Thus, replacing standard electric motors by high efficiency electric motors is necessary and this measure is one of the best available techniques [17]. To illustrate the successfulness of the proposed model, this paper applies this model as support tool to alternative selection for replacing standard electric motors by high efficiency electric motors.

Case study method

There are 5 typical steps: (1) - inventory of all existing motors at the factory together with main parameters such as capacity, operation time,...; (2) – Classifying the motors having similar nature into groups; (3) – Calculating the waste emission of the motors based on the consumed electricity and emission coefficient; (4) – Proposing the alternatives for motors, calculating the emission and cost for each alternative; (5) – Setting the program for transferring the mathematical formulas at section 3 into Lingo language, and the model is resolved by using this language.

Results

The firm A has 168 electric motors with output power range 0.75 kw – 200 kw that are divided into 4 and 6 pole motor. In this study, CO_2 is used as an environmental indicator, CO_2 emission factor for electricity in Vietnam is 0.5657 kg $CO_{2equivalent}$ per Kwh [18]. The alternatives are gotten from database of high efficiency electric motors of motor manufacturers such as ABB, SIEMENS, Brook Crompton. Table 2 is an example of the selection of alternatives. Similarly, alternatives for all 168 electric motors are chosen. Then all electric motors are divided into 29 groups (N = 29), each group comprises subjects (motors) that similar power, emissions and alternatives. Table 3 is an example of one group. All alternatives of each group and their properties are described as Table 4 and Table 5.

Table 2. Alternatives for 4 poles, 22kw electric motor

No.	Manufacturer	Model	Power	Number of poles	Efficiency (%)	Efficiency class (IE)	Cost (VND)[*]
1	ABB	M3BP 180-MLB 4	22	4	92.3	IE2	73,335,815
2	ABB	M3BP 180-MLB 4	22	4	93.3	IE3	75,023,609
3	Brook Crompton	WU-DA180LJ	22	4	91.6	IE2	71,072,523

Table 3. Alternatives and their properties of an example group

Alternative	Sign	Description	Emission, kgCO$_2$/day	Investment cost, VND
Baseline – without innovation	X_{10}	DT1 group: P=4kw, 6 poles, operation time: 15 hrs/day	41.7	0
Option 1	X_{11}	ABB-M3BP 132 SMC 6	39.98	26,101,370
Option 2	X_{12}	ABB-M3BP 132 SMF 6	39.1	29,595,815
Option 3	X_{13}	Brook Crompton-WU-DA132MMX	40.12	26,933,209

Table 4. Emission values of all options and their alternatives

Quantity, q	Group	Option 0 (X_{i0})	Option 1 (X_{i1})	Option 2 (X_{i2})	Option 3 (X_{i3})
3	DT$_1$	12,509.34	11,993.64	11,731.11	12,036.17
6	DT$_2$	7,026.89	6,519.71	6,459.55	6,643.45
27	DT$_3$	12,253.43	11,731.11	11,492.78	11,758.20
8	DT$_4$	16,530.19	15,731.54	15,556.75	15,910.31
4	DT$_5$	300,130.23	294,449.53	293,523.58	293,523.58
10	DT$_6$	62,296.22	60,676.38	60,026.05	61,140.07
1	DT$_7$	541,627.66	532,562.76	530,343.75	524,876.29
3	DT$_8$	246,353.23	241,930.83	240,660.19	237,664.42
1	DT$_9$	106,188.33	100,844.81	99,250.84	99,776.54
9	DT$_{10}$	152,020.36	148,789.32	147,070.12	146,915.79
13	DT$_{11}$	3,733.62	3,349.54	3,329.63	3,440.07
4	DT$_{12}$	43,049.32	41,777.63	41,236.23	42,146.52
6	DT$_{13}$	152,020.36	148,316.47	146,761.79	146,915.79
8	DT$_{14}$	2,727.48	2,425.97	2,419.82	2,515.46

9	DT$_{15}$	22,200.44	21,380.04	21,119.88	21,524.66
3	DT$_{16}$	84,200.11	81,941.52	80,899.89	81,766.06
16	DT$_{17}$	4,946.21	4,529.63	4,476.52	4,611.68
5	DT$_{18}$	2,648.04	2,357.08	2,314.23	2,398.54
2	DT$_{19}$	205,958.74	202,035.71	200,972.37	198,465.44
1	DT$_{20}$	60,414.56	60,676.38	60,026.05	61,140.07
3	DT$_{21}$	124,922.85	121,996.01	120,330.09	120,965.42
1	DT$_{22}$	434,226.01	426,050.21	425,160.75	425,160.75
12	DT$_{23}$	31,965.92	30,975.83	30,371.10	31,182.80
1	DT$_{24}$	134,720.18	131,106.44	129,439.83	130,825.70
4	DT$_{25}$	68,878.92	66,844.20	65,977.97	67,434.44
3	DT$_{26}$	7,913.94	7,247.40	7,162.44	7,378.70
1	DT$_{27}$	329,533.98	323,257.14	321,555.79	317,544.70
3	DT$_{28}$	4,236.87	3,771.33	3,702.76	3,837.66
1	DT$_{29}$	99,673.95	97,082.21	96,041.67	97,824.10

Table 5- Cost of alternatives of all options

Group	Option 0 (X$_{i0}$)	Option 1 (X$_{i1}$)	Option 2 (X$_{i2}$)	Option 3 (X$_{i3}$)
DT$_1$	0	26,101,370	29,595,815	26,933,209
DT$_2$	0	12,646,565	14,001,554	12,090,319
DT$_3$	0	17,139,424	18,518,185	17,067,292
DT$_4$	0	21,347,022	22,155,261	20,452,987
DT$_5$	0	304,230,717	308,628,489	327,717,195
DT$_6$	0	73,335,815	75,023,609	71,072,523
DT$_7$	0	467,067,130	496,258,825	517,463,217
DT$_8$	0	186,299,119	195,641,413	205,791,945
DT$_9$	0	85,982,380	92,139,261	87,587,946
DT$_{10}$	0	126,418,109	131,647,891	131,838,989
DT$_{11}$	0	9,342,293	9,651,326	9,381,763
DT$_{12}$	0	48,827,152	50,728,891	48,171,678
DT$_{13}$	0	118,407,032	124,349,967	121,783,473
DT$_{14}$	0	6,133,109	7,606,957	6,368,494
DT$_{15}$	0	28,026,880	29,714,674	27,793,176
DT$_{16}$	0	69,342,163	71,695,565	71,709,034
DT$_{17}$	0	10,340,707	10,816,141	10,363,614

DT_{18}	0	7,488,098	7,963,533	7,756,629
DT_{19}	0	152,852,282	165,926,739	174,864,913
DT_{20}	0	73,335,815	75,023,609	71,072,523
DT_{21}	0	99,865,076	111,204,196	105,938,417
DT_{22}	0	362,732,967	427,368,326	448,501,402
DT_{23}	0	36,869,967	40,031,609	34,574,724
DT_{24}	0	69,342,163	71,695,565	71,709,034
DT_{25}	0	48,827,152	50,728,891	48,171,678
DT_{26}	0	10,340,707	10,816,141	10,363,614
DT_{27}	0	152,852,282	165,926,739	174,864,913
DT_{28}	0	7,488,098	7,963,533	7,756,629
DT_{29}	0	73,335,815	75,023,609	71,072,523

A total of 29 groups with 168 subjects can be replaced and each subject has three alternatives. With a large number of subjects and alternatives, it consumes a lot of time to solve by manual. Therefore, to analyze the performance of the proposed model and the interactive solution method, the model is coded and solved by LINGO 9.0 optimization software. As mention in section 3, the proposed model has two cases. However, they are similarity to each other. So in this paper, the case 1 is used in performance testing with different reduction objective Z_0. Z_0 is calculated by formulation:

$$Z_0 = a\% \ Z_{max}$$

Whereas, a = 0 to 100%; Z_{max} is maximum emission reduction potential of all subjects. Z_{max} can be calculated as follows.

$$Z_{max} = \sum_{i=1}^{n=29} q_i \left(E_{i0} - \operatorname*{Min}_{j=1 \to m_i} E_{ij} \right)$$

With a = 5%, 10%, 50% and 100%, the results are reported in Table 6.

Table 6. The summary of results regarding different levels

Group	Quantity, item	Number of selected alternatives			
		a=5%	a=10%	a=50%	a=100%
DT_1	3	0	0	0	$3X_{12}$
DT_2	6	0	0	$1X_{22}$	$6X_{22}$
DT_3	27	0	0	$13X_{32}$	$27X_{32}$
DT_4	8	0	0	$8X_{42}$	$8X_{42}$
DT_5	4	0	0	0	$4X_{52}$
DT_6	10	0	0	0	$10X_{62}$
DT_7	1	0	0	0	$1X_{73}$

DT_8	3	0	0	$3X_{83}$	$3X_{83}$
DT_9	1	$1X_{92}$	$1X_{92}$	$1X_{92}$	$1X_{92}$
DT_{10}	9	0	0	0	$9X_{103}$
DT_{11}	13	0	0	$\mathbf{2X_{111} + 11X_{112}}$	$13X_{112}$
DT_{12}	4	0	0	0	$4X_{122}$
DT_{13}	6	0	0	$6X_{132}$	$6X_{132}$
DT_{14}	8	0	$2X_{141}$	$\mathbf{8X_{141}}$	$\mathbf{8X_{142}}$
DT_{15}	9	0	0	0	$9X_{152}$
DT_{16}	3	0	0	$3X_{162}$	$3X_{162}$
DT_{17}	16	0	0	$16X_{172}$	$16X_{172}$
DT_{18}	5	0	$1X_{182}$	$3X_{182}$	$5X_{182}$
DT_{19}	2	0	0	$2X_{193}$	$2X_{193}$
DT_{20}	1	0	0	0	$1X_{202}$
DT_{21}	3	0	0	$3X_{212}$	$3X_{212}$
DT_{22}	1	0	0	0	$1X_{222}$
DT_{23}	12	0	0	0	$12X_{232}$
DT_{24}	1	$1X_{242}$	$1X_{242}$	$1X_{242}$	$1X_{242}$
DT_{25}	4	$1X_{252}$	$2X_{252}$	$4X_{252}$	$4X_{252}$
DT_{26}	3	$1X_{262}$	$3X_{262}$	$3X_{262}$	$3X_{262}$
DT_{27}	1	0	$1X_{273}$	$1X_{273}$	$1X_{273}$
DT_{28}	3	$1X_{281} + 2X_{282}$	$3X_{282}$	$3X_{282}$	$3X_{282}$
DT_{29}	1	0	0	$1X_{292}$	$1X_{292}$
Optimal cost, VND		248,795,000	516,726,000	3,737,726,000	9,325,994,000
reduction, kg CO_2 per year		17,404	34,802	173,967	347,934

If the emission reduction goal is 5%, 10%, and 50% of Z_{max}, the investment cost of these cases are 249 million VND, 518 million VND and 3,738 million VND. The budget used for improvement at the factory is estimated about 3-4 bill. VND/year, thus, the target "50% reduction compared with maximal emission reduction norm" is suited with the condition at the company (According to the item 10, section 1, degree Nr 78/2014/TT-BTC dated on 18/6/2014 of the Ministry of Finance, the company could take maximally 10% of the profit (tax included) for setting up the fund for research and development; The average income (tax included) of the company is about 30-40 bill VND/year, thus the budget leaving for improvement is estimated to be about 3-4 bill VND/year). In case of a = 100%, results show that maximization of emission reduction potential of the firm A in case of replacing all standard electric motors is 347,934 kg CO_2 per year (equivalent to about

700,000 Kwh saving per year) and can reduce the overall electricity by 3,7% which is close to the previously reported in Europe (2-8% [17]). To achieve this objective, the minimization of investment cost is 9,325 million VND (1 USD =21,920 VND). The cost for replacement standard motors by high efficiency motors is high because the additional initial purchase cost may be 20 – 30% or higher for motor greater than 20 kW or may be 50 – 100% higher for motor less than 15 kW, depending on the energy savings category [17]. In cassava starch production, cost of electricity shares 9% of total production cost[19], so using high efficiency motors can reduce by 0,36% production cost. This is just a potential of emission reduction by using high efficiency motors, thus, potential reduction and savings also comes from other subjects such as waste water and waste heat recovery, good housekeeping [16, 19].

5. CONCLUSION

The limited use of systematic techniques and tools is one of the main barriers pointed out in the extant literature. To overcome barriers in case of alternative selection of CP program under multi-subject and multi-alternative conditions, this study proposes an optimal mathematical model to determine optimal. The effectiveness of the optimization model is investigated through a real case. The result obtained from case study showed that with given potential budget used for improvement at the factory of 3 – 4 bill VND/year, the factory could reduce 50% greenhouse gases from electricity through the use of high efficiency motors. Results also indicate that using simple comparison and the weighted scoring method for the selection of subjects for innovation and their cleaner production option can reject other potential alternatives. One way to accomplish this problem, all alternatives should be considered base on the goal of reduction or budget for innovation in order to setting up the best plan for CP implementation.

Besides considering the goal of emission reduction and the budget in the alternative selection, the firm might be interested in other criteria. This research applies only for the case of greenhouse gases reduction from electricity consumption by using high efficiency motors, therefore, many possible future research directions can be defined in this area.

Mô hình quy hoạch nguyên áp dụng cho lựa chọn phương án và lập kế hoạch trong chương trình sản xuất xuất sạch hơn: điển hình cho giảm thiểu khí nhà kính

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TÓM TẮT

Lựa chọn đối tượng (như dòng thải, quá trình, thiết bị...) để cải tiến và phát triển các phương án thay thế để triển khai trong chương trình thực hiện sản xuất sạch hơn tại nhà máy sao cho đạt hiệu quả tối ưu là một vấn đề khó khăn và phức tạp, nhất là trong trường hợp có nhiều đối tượng có thể cải tiến và mỗi đối tượng có nhiều phương án thay thế. Bài toán đặt ra trong trường hợp này là đối tượng nào cần cải tiến và phương án ứng với mỗi đối tượng là gì để đạt được mục tiêu giảm thiểu tối đa với chi phí đầu tư thấp nhất. Để khắc phục khó khăn này, bài báo này đề xuất mô hình toán tối ưu nhằm hỗ trợ lựa chọn phương án trong triển khai chương trình SXSH. Trong nghiên cứu này mô hình quy hoạch nguyên được áp dụng trong bước phân tích phương án thay thế và thiết lập kế hoạch triển khai chương trình SXSH. Mô hình đề xuất đã được áp dụng điển hình vào nhà máy sản xuất tinh bột khoai mì ở Tây Ninh, Việt Nam (nơi tập trung nhiều cơ sở sản xuất tinh bột mì nhất nước) để đề xuất giải pháp giảm thiểu khí nhà kính và tiêu thụ điện năng. Kết quả cho thấy mô hình này là một phương pháp mới, hiệu quả để áp dụng cho quá trình lựa chọn phương án và thiết lập kế hoạch thực hiện trong SXSH, nhất là trong trường hợp có nhiều đối tượng và phương án thay thế. Cách giải mô hình này có thể tổng quát hoá để áp dụng cho trường hợp đối tượng cần cải tiến và phương án thay thế với số lượng không hạn chế.

Từ khóa: quy hoạch mục tiêu, sản xuất sạch hơn, ngăn ngừa ô nhiễm công nghiệp, sản xuất tinh bột mì, hệ thống hỗ trợ ra quyết định.

REFERENCES

[1]. Cagno, E., P. Trucco, and L. Tardini, *Cleaner production and profitability: analysis of 134 industrial pollution prevention (P2) project reports.* Journal of Cleaner Production **13**, 593-605(2005).

[2]. Nhân, T.V., N.T.L. Giang, and N.T. Phương, *Từ phổ biến và xúc tiến áp dụng SXSH đến xây dựng mô hình sản xuất và tiêu thụ bền vững (Cleaner production promotion toward sustainable production and consumption model), in Vietnamese*, in

4th *Vietnam national roundtable workshop on sustainable production and consumption.* 2009: Huế city, Viet Nam. p. 10-20.

[3]. Luken, R.A., *A programmatic review of UNIDO/UNEP national cleaner production centres.* Journal of Cleaner Production. **12**, 195–205(2004).

[4]. Shi, H., et al., *Barriers to the implementation of cleaner production in Chinese SMEs: government, industry and expert stakeholders' perspectives.* Journal of Cleaner Production. **16**, 842-852(2008).

[5]. Mitchell, C.L., *Beyond barriers: examining root causes behind commonly cited Cleaner Production barriers in Vietnam.* Journal of Cleaner Production. **14**, 1576-1585(2006).

[6]. Silva, D.A.L., et al., *Quality tools applied to Cleaner Production programs: a first approach toward a new methodology.* Journal of Cleaner Production. **47**, 174-187(2013).

[7]. Hong, J. and X. Li, *Speeding up cleaner production in China through the improvement of cleaner production audit.* Journal of Cleaner Production. **40**, 129-135(2013).

[8]. Jones, D.F. and M. Tamiz, *Chapter 3 - Goal programming in the period 1990-2000*, in *Multiple criteria optimization.* 2002, International Series in Operations Research & Management Science p. 129-170.

[9]. Chang, C.-t. and J.-R. Hwang, *A multiobjective programming approach to waste minimization the utility systems chemical processes.* Chemical Enoineerin 9 Science. **51**(16), 3965 -3965(1996).

[10]. Chakraborty, A. and A.A. Linninger, *Plant-Wide Waste Management. 1. Synthesis and Multiobjective Design.* Ind. Eng. Chem. Res. **41**, 4591 4604(2002).

[11]. Costi, P., et al., *An environmentally sustainable decision model for urban solid waste management.* Waste Management. **24**, 277–295(2004).

[12]. Mavrotas, G., *An integrated approach for the selection of Best Available Techniques (BAT) for the industries in the greater Athens area using multi-objective combinatorial optimization.* Energy Economics **29**, 953–973(2007).

[13]. Ghobadi, A., S.A. Darestani, and K. Shahroudi, *Impact of Closed–Loop Supply Chains on Reducing Carbon Emission and Gaining Competitive Advantage: NSGA-II and MOPSO Solutions.* Indian Journal of Science and Technology. **8**(35)(2015).

[14]. VNCPC, *Mini-guide to Cleaner Production.* 2000.

[15]. CPI and VNCPC, *Tài liệu hướng dẫn SXSH trong công nghiệp: ngành sản xuất tinh bột khoai mì (Guideline on cleaner production in cassava starch production), in Vietnamese.* 2010: Hà Nội.

[16]. Sriroth, K., *Cassava Starch Technology: The Thai Experience.* Starch/Stärke. **52**, 439–449(2000).

[17]. European Commission, *Reference document on best available techniques for energy efficiency.* 2009.

[18]. NOCCOP, *Emission factor of Vietnam Grid, in Vietnamese, Department of meteorology, hyrology and climate change.* 2015.

[19]. Chavalparit, O. and M. Ongwandee, *Clean technology for the tapioca starch industry in Thailand.* Journal of Cleaner Production. **17**, 105–110(2009).