Decision planning in agricultural production for achieving the Green Economy of Mae faek, Sansai District, Chiang Mai Province

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Abstract

The research is to study decision toward using producing factors appropriately under the green economy concept and community economic sustainability of 250 agricultural households who grow glutinous rice, animal feed maize and potato in the areas of 2,500 Rai in Tambol Mae-faek Mai, Sansai District, Chiang Mai. The study employs methodology of Fuzzy Analysis Hierarchical Process: AHP together with Multi-goal and Multi-Period Linear Programming.

The result reveals that growing in-season glutinous rice alternating with potato is the most appropriate way to increase net revenue and decrease amount of green house effect released, followed by growing in-season glutinous rice alternating with animal feed maize as this helps income stability when drought occurs. On the other hand, growing in-season glutinous rice alternating with off-season glutinous rice not only risks lack of water resource but also affects in increasing amount of green house gas from growing process.

Keywords: 1) Multi-criteria decision 2) Extended goal programming 3) Green economy 4) trade-offs 5) Cropping system

1. Introduction

The 11th National Economic and Social Development Plan set many important strategies to help emerging economic restructuring for sustainable and environmentally-friendly producing and consuming or toward green economy. Activities under that approach include using resources efficiently, causing green house gas in less amount that does not affect environment, not causing imbalance that is important in order to sustain human living, and supporting ways of lives of people in every sector. (Ministry of Agriculture and Cooperatives 2013) This approach is one of significant factors of sustainable development (Newton and Cantarello, 2014) Moreover, the ministry has set appropriate zoning for economic crops for each area with another approach i.e. collaborative farming. The goal is to grow crops according to potential of each area and reduce the budget to make agriculturists be more competitive. Practicality of doing this is to collaborate agriculturists in the appropriate area to plan production and marketing together.

Tambol Mae Faek Mai, Sansai District is an important economic crop growing area in Chiang Mai. It has both plain and highland landscapes large enough to crop growing. It also has fertile soil, water and irrigation, suitable for many economic crops, especially rice, maize and potato, considered as Thailand's important economic crops. However, with previous approach of agriculturist community that focused on marketing, this caused negative impact toward economy, environment and society. That is, 1) agricultural household debt from rising budget while product price falling causing continuous deficit; 2) uncertainty of environment, both from drought and flood, resulting in water usage planning. This includes climate change that directly affects amount of crop yield. So, agriculturists turned to use more chemical fertilizer that caused effect to soil fertility and chemical residue in natural water supply.

From the above mentioned issues reflecting global and Thailand problems and policy direction, this means there emerges the need to move 3 important pillars (economy, society and environment) toward the concept of green economy and sustainable economic growth. However, goal that needs achievement of successful community economy and environment-friendly situation are contradicting each other. This makes it difficult to plan or mange local resources in reality. Therefore, this research aims to analyze decision making to use resources to achieve both goals (economy of community together with reducing green house gas from agriculture) according to green economy concept to make community economy sustainable.

2. Literature review

Multiple criteria decision making: MCDM and multiple objective decision making: MODM are widely accepted in sustainable agricultural and energy development researches. This is because the objective of such researches involves society, economy and environment system, considered to be important factors of green economy. Researches that apply MCDM and MODM for sustainability can be classified into: 1) choosing criteria; 2) weighing; and 3) analysis of MCDM. The criteria choosing can be divided into 4 types: (1) technical criteria, most of them are related to efficiency; (2) economic criteria, which focuses on lowering budget and making more economically benefit (Jovanovic et al., 2009); (3) environment criteria, related to the releasing of gas types of NOX and CO2, including land use for agriculture that directly affect environment and landscape (Pilavachi et al., 2009); (4) social criteria, related to job creation which would result in income and quality of life of people in the community (Doukas et al., 2007). Weighing is significant approach in prioritizing importance of criteria and alternative. Widely used weighing for analyzing and evaluating can be classified into 2 groups: 1) subjective weighting method i.e. weighing by using satisfaction scores from decision makers such as AHP (Aras H, 2004) as weight value in each level can be calculated in many ways e.g. arithmetic mean; 2) objective weighting methods i.e. calculating weighing approach by using information, differences of weight value, like Entropy method (Wang et al., 2008). Moreover, conventional MCDM assume value as definite number, but in real world, most decision makings are in uncertain and fuzzy situations. So, there has been an application of Fuzzy Set Theory presented by Zadeh in 1965, employing with MCDM as energy evaluation which consideration on economic, social and environment factors (Wang et al., 2008). There has also been participatory method among decision makers in MCDM analysis such as MODM (as in Chebyshev Goal Programming) together with FAHP in allocation of land usage of Holland (Stewart et al., 2004), model of crop growing in India with Fuzzy goal programming (FGP) (Biswas, 2005). Moreover, calculating result of MODM would give ratio of trade-offs that reflect resource scarcity. Beck et al. (2008) set goal of energy plan and calculated trade-offs between economy, society and environment to see opportunity cost from choosing certain alternative.

3. Methodology

This study employs MCDM which consists of 2 main parts: 1) Fuzzy Analysis Hierarchical Process: FAHP. This is to know weight value agriculturists give toward alternatives in crop growing and selling; 2) Developing model of Multi-Period and Multi-goal Linear Programming: MpMGP) together with Extended goal programming (EGP). Weight values from FAHP would be used in objective equation in mode of EGP as following details.

3.1 Population and sampling

To make area use planning become practical, the researchers chose potential areas and sampling population willing to give information. That is, areas in Tambol Mae Faek Mai, Sansai District, Chiang Mai. Types of crops being grown include: 1) in-season glutinous rice alternating with potato; 2) in-season glutinous rice alternating with maize for animal feed; and 3) in-season glutinous rice alternating with off-season glutinous rice. Total population growing those 3 types of crops total 420 households. When considering size of sampling from Krejcie & Morgan method, together with readiness of grouping for collaborative production plan, sampling size becomes 250 households. Field data collection was done from the crop growing year of 2016-17 together with secondary data from statistics and relevant researches to gain parameter value in the model.

3.2 Data analysis method

1) Decision making with Fuzzy Analysis Hierarchical Process(FAHP) is a method in multi criteria decision making process (MCDM) to solve complex and fuzzy problems by using the best alternatives. This includes concept of fuzzy set theory together with MCDM for benefit of pairwise comparison that is uncertain or fuzzy. Such process is applied with participatory meeting to bring about weight values for criteria and alternatives as in Figure 1.

2) Development of Multi-Period and Multi-goal Linear Programming (MpMGP) from participatory meetings eventually yield objective equation. That is, highest revenue from 1) in-season glutinous rice alternating with potato; 2) in-season glutinous rice alternating with maize for animal feed; and 3) in-season glutinous rice alternating with off-season glutinous rice. As for objectives No. 4-6 are green house gas emission from the first three alternative equations. Crop growing is divided into 3 parts: growing, taking care, and harvesting together with selling. To make it continuous with production plan, multi-period model would include time period for decision of 48 months as shown by following model and parameter.

2.1) objective equation showing highest net **revenue objective equation** (Z_b) from growing and selling products from 3 alternatives (from method of FAHP)

$$Z_b = \sum_{t=1}^{T}\left(P_{it}\cdot Y_{it}\right)\cdot Area_{it(j=3)} - \sum_{i}^{I}\sum_{t=1}^{T}\sum_{j=1}^{J}\left(Cl_{ij}\right)\cdot Area_{itj} - \sum_{i}^{I}\sum_{t=1}^{T}\sum_{j=1}^{J}\left(CH_{ij}\right)\cdot HiLa_{itj} \qquad (1)$$
$$- \sum_{i}^{I}\sum_{t=1}^{T}\sum_{j=1}^{J}\left(CW_{ij}\right)\cdot HiW_{itj} \quad \forall b \quad b=1,\ldots,3$$

Objective equation of lowest CO_2 amount (Z_c) from growing according to equation (1), that is,

$$Z_c = \sum_{i}^{I}\sum_{t=1}^{T}\left(FC_i\cdot Y_{it}\right)\cdot Area_{it(j=3)} \quad \forall c \quad c=4,\ldots,6 \qquad (2)$$

Selling price of product (P_{it}) and **average yield of crops** (Y_{it}) From field survey of agriculturist sampling during crop season of 2013 – 2017, selling price and yield amount of agricultural products become range of data (lowest – highest). This is because each agriculturist has different production efficiency, together with deviation of data from agriculturists, resulting in uncertain, fuzzy information. Moreover, CO_2 amount from crop growing can be calculated from **average crop yield** (Y_{it}) timing with **value of factor of CO emission of each crop** (FC_i) (Thailand greenhouse gas management organization, 2017) as shown in parameter value in Table 1.

Budget of cost of producing crops (Cl_{ij}) By using data of crop year 2014/15 from glutinous rice farmers (both in and off season), maize for animal feed, and potato, we can get average budget relevant to important production activities i.e. growing(hired labor, seeds, and soil preparation), taking care (hired labor, fertilizer, hormone and crop pesticide), and harvest (hired labor) as shown in Table 1.

Table 1 parameter value of objective equation

crops	Budget of production (baht/Rai) (CI_{ij})			Average price (baht/Kg.) (P_{it})	Average yied (Kg./Rai) (Y_{it})	CO amount(kgCO/Rai) $(FC_i \cdot Y_{it})$
	grow	care	harvest			
In-season glutinous rice	2,314	1,016	600	8.5 - 15	650 – 1,000	991.25 – 1,525
Off-season glutinous rice	2,770	876.6	714	9.5 - 15	600 – 800	759.6 – 1,012.8
Maize for animal feed	2,075	770	733	6.5 - 9	722 – 750	192.7 – 200.2
Potato	5,880	3,275	475	9.5 - 12.5	2,800 – 3,500	341.6 – 427

Source: from the survey

2.2) Equation of Constraints consists of water and soil resources and labor.

2.2.1) Constraints in water resource include water transfer during dry and rainy seasons, including water amount used by crop growing as set by zoning as shown in equation (3)

$$
\begin{aligned}
&TrW_{t(w=1)} - HiW_{t(w=2)} \leq WatQ_{t(w=1)} \quad \exists t \\
&TrW_{t(w=1)} - TrW_{(t-1)(w=1)} \leq HiW_{t(w=2)} \quad \exists t \\
&\sum_{i=1}^{I}\sum_{j=1}^{J}\left(CWU_{ij}\right)\cdot Area_{itj} + TrW_{t(w=1)} - TrW_{(t-1)(w=1)} \leq WatQ_{t(w=3)} \quad \exists t\ \exists i
\end{aligned} \tag{3}
$$

Constraints of groundwater usage during dry and rainy seasons are shown in equation (4)

$$
\begin{aligned}
&\sum_{t=1}^{T} HiW_{t(w=2)} \leq WQR_{w=2} \quad \exists t \\
&\sum_{t=1}^{T} HiW_{t(w=4)} \leq WQR_{w=4} \quad \exists t
\end{aligned} \tag{4}
$$

Irrigation water amount $(WatQ_{tw})$ **groundwater** (WQR) and **ratio of water usage by crops** (CWU_{ij}). Since the studied areas are in irrigation system, so lack of water is not much of a problem. However, due to climate uncertainty, water amount is set as fuzzy. From interview with agriculturists and irrigation experts, we know that amount of water that can be used for agriculture during dry season (Jan – May) is 70–550 thousand cubic meters/month, during rainy season (Jun – Aug) 550–1,000 thousand cubic meters/month (Irrigation Department, 2014.) Moreover, Mae Faek Mai can use groundwater as reserved water. From estimation of experts, this amount totals around 0–50 thousand cubic meters/month. As for **ratio of water used by crops** (CWU_{ij}), off-season glutinous rice has the highest ratio as shown in Table 2.

2.2.2) Constraints on appropriate zone for crop growing in the studied areas: the overall use of land for all crop growing activities would have value not over the size of **soil series** $(Aland_{st})$

$$
\sum_{i=1}^{I}\sum_{j=1}^{J} Area_{itj} \leq Aland_{st} \quad \forall t\ \forall i \tag{5}
$$

Areas of harvesting and taking care activities would be less than that for growing.

$$
\begin{aligned}
Area_{i(t+1)(j=2)} &\leq Area_{i(t)j(j=1)} \quad \forall t \quad \forall i \\
Area_{i(t+2)(j=2)} &\leq Area_{i(t+1)(j=2)} \quad \forall t \quad \forall i \\
Area_{i(t+3)(j=3)} &\leq Area_{i(t+2)(j=2)} \quad \forall t \quad \forall i
\end{aligned}
\tag{6}
$$

Areas that is suitable for crop growing $(Aland_{itj})$ Soil series used for decision planning include soil that is suitable for altitude and in irrigation areas around 5,436 Rais. (Land Development Department, 2550.) However, to make management efficient and in-time practicality, stakeholders decided that land use would be 45% or roughly 2,500 Rais.

2. 2. 3) Constraints on household labor and hired labor for growing and harvesting activities. Equation No. (6) is the use of labor for activity of crop which has value no more than **household labor** (AL_t) plus **hired labor** (HiL_{it})

$$\sum_{i=1}^{I}\sum_{j=1}^{J}(LQ_{ij})\cdot Area_{ijt} - \sum_{i=1}^{I} HiL_{it} \leq AL_t \quad \exists i \;\; \forall t \tag{7}$$

Amount of highest hired labor for crop at time has value no more than available hired labor $(AHiL_t)$.

$$\sum_{i=1}^{I} HiL_{it} \leq AHiL_t \quad \exists i \;\; \forall t \tag{8}$$

Raito of labor usage in growing activity (LQ_{ij}) From field survey, we know ratio of labor use for growing, taking care and harvesting (Table 2.) Growing includes soil and seed preparation, growing seeds. These are activities that use the most average man-hour. Potato is the crop that need care more than any other corps. Maize for animal feed use the least average man-hour since it is easy to take care and can withstand drought, not much affected by diseases. Agriculturists can use only household labor for growing it.

Table 2 man-hour use for growing activity and water usage of crops

crops	Labor use (man-hour/Rai) (LQ_{ij})			Water used by crops (cbm/Rai) (CWU_{ij})
	grow	care	harvest	
In-season glutinous rice	18.0	6.4	12.5	650-1,050
Off-season glutinous rice	17.5	7.1	13.0	750-2,009
Maize for animal feed	16.0	3.1	10.5	400-600
Potato	24.0	8.0	16.0	500-650

Source: from the survey

Household labor amount (AL_t) and **hired labor already living in the area** $(AHiL_t)$. Averagely there are 3 members working in agriculture per household. Hired labor in the studied and nearby areas averagely total 25 – 200 persons. (Chiang

Mai community development department, 2016) As setting 1 person working 8 hours per day and 25 days per month, calculating hours of household labor are 5,000 and hired labor are 5,000 – 40,000 man-hour / month.

Specifying Sets

i type of crop $i \in I$ $I = 1$ in-season glutinous rice $I = 2$ off-season glutinous rice $I = 3$ potato $I = 4$ maize for animal feed

S type of suitable soil series $s \in S$ $S = 1$ number one suitable soil series

t time period of agricultural activities $t \in T$ month 1 – 48

j crop growing activity $j \in J$ $J = 1$ growing $J = 2$ taking care $J = 3$ harvesting

w water supply in growing areas $w \in W$ $W = 1$ irrigation water $W = 2$ groundwater

Decision Variables

$Area_{itj}$ land usage of crop i for growing activity j at time t of suitable soil series S (unit: Rai)

$HiLa_{itj}$ amount of hired labor (unit: man-hour)

HiW_{itj} amount of groundwater usage during dry and rainy seasons at time t (unit: cubic meter)

TrW_{tw} amount of irrigation left from agricultural activities at time t (unit: cubic meter)

$TrW_{(t-1)w}$ amount of irrigation water transferred at time t (unit: cubic meter)

HiL_{it} amount of hired labor at time t (unit: man-hour)

Since parameter of some decision variables is of uncertain data e.g. economic factor (product price, labor amount), environment factors (water amount, crop yield) and goal of CO amount, membership function is set as Fuzzy min while goal value of net revenue has membership function as Fuzzy max (Sakawa et al., 2013.)

3) Finding appropriate values by Extended goal programming (EGP) Since results of calculation of multi-purpose and multi-period model yield many values of resource allocation efficiently according to pareto principle and can cause imbalance of results. That is, only crops that have efficiency in income that are chosen to be grown. So, to set criteria for choosing alternative appropriately, EGP model is applied so that resources allocation would be balance among philosophy of efficiency or weighted goal programming (WGP) and philosophy of equity or Chebyshev goal programming (CGP) (Jones et al., 2016). So, EGP model can demonstrate the possible mixture of two contradicting entity: efficiency and equity under goal to be achieved.

4. Empirical results

4.1 Making decision with Fuzzy Analysis Hierarchical Process: (FAHP)

The objectives of participatory meetings among stakeholders including agriculturists, government agents such as sub-district agricultural and sub-district administrative officers and academicians from educational institution, are to set weight importance for alternatives or 6 objective equations by using method of FAHP. This results in figure showing levels revealing goal of the community, that is, having sustainable income from agricultural products. (Figure 1). This comprises important criteria including economy and society (ES) having the highest value of weight as 0.75 higher than that of health and environment which have value at 0.25. When we consider sub-criteria, calculation result reveals that in economic and social criteria, agriculturists give important weight to price (p) criteria the most, followed by government support (gov). Health and environment criteria received importance from agriculturists in part of chemical residue in their body (che) the most because they have chemical residue in their bodies above average standard.

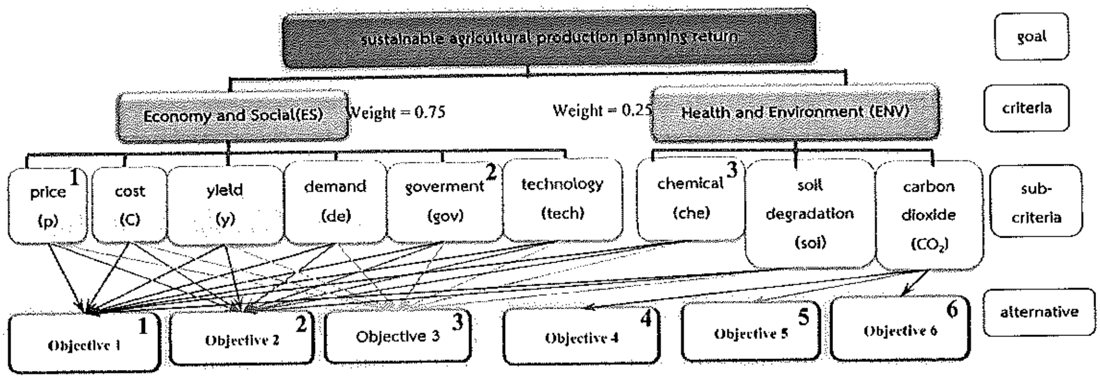

Figure 1 Hierarchical analysis to the sustainable agricultural production planning return (Mae Faek Mai, Amphoe San Sai, Chiang Mai Province)

When considering value of global weight of all 6 alternatives, the study reveals that weight values of objective 1-3 total more than 0.7 because community people give importance to economic and social criteria (ES) more than health and environment (objective 4-6). Alternative that has highest weight value is objective 1 (revenue from in-season glutinous rice and potato) because this alternative can achieve goal of revenue and food sustainability in community level, having weight value at 0.412, followed by objective 2 (revenue from in-season glutinous rice and maize for animal feed) and 3 (revenue from in-season and off-season glutinous rice) with weight value at 0.211 and 0.142 respectively. This is because agriculturists consider uncertainty from drought. So, maize for animal feed from objective 2 is risky in term of revenue. In parts of health and environment criteria, overall weight value of alternatives from objective 4–6 total less than 0.3. This is because community people consider that CO amount released from agricultural activities does not concretely affect their living or economic benefit. From calculation, it is found that objective 6 (CO_2 from objective 3) has the highest volume of green house gas. (1,977 kg CO_2/Rai) followed by objective 4 (CO_2 from objective 1) and 5 (CO_2 from objective 2) respectively. Nevertheless, agriculturists still give weight to objective 4 with global weight value as 0.105 followed by objective 5 and 6 as 0.08 and 0.05 respectively.

4.2 Achieving revenue goal of agriculturists and approach for appropriate resource allocation

From participatory meetings among agriculturists' representatives and community economic data collected by sub-district administrative office, this gives range of data and net revenue and CO_2 amount to set as goal value along 3 years for MpMGP model. That is, objective 1 (in-season glutinous rice, potato) 3 – 50 million baht, objective 2 (in-season glutinous, maize) and objective 3 (in-season and off-season glutinous rice) 1.5 – 30 million baht, while objective 4–6 include need to reduce amount of CO_2 as low as possible. Range of goal values are similar for 3 alternatives i.e. 0.5 – 20 million kg CO_2 and with setting controlling parameter λ in EGP model to identify philosophy of solution needed i. e. increase of revenue **efficiency** (λ increase to 1) or increase of **equity of all objectives** (λ reducing to 0). This result can be shown in Figure 2.

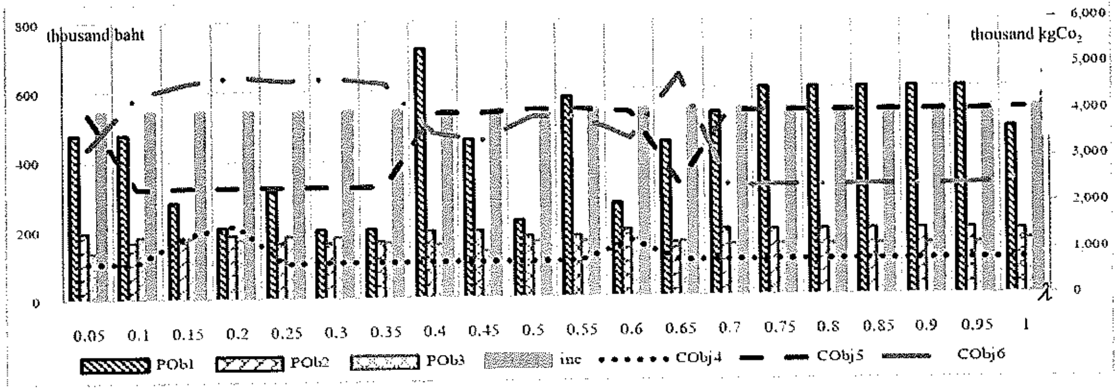

Figure 2 Return on household and amount of carbon dioxide emissions at various level of λ

Focusing on efficiency in achieving goal of each objective: The result shows that alternative objective that has highest weight value would be chosen first followed by objective that has second order value. From Figure 2, revenue from objective 1 (Pob1) has value high as 15 million baht/year or averagely income per household as 2 hundred thousand baht/year (at $\lambda \geq 0.7$) which is higher than present average income at 1.8 hundred thousand baht/ year (inc) (Chiang Mai Provincial Community Development, 2016) together with lowest emission of CO_2 amount (CObj4). The second alternative is objective 2 (Pob2) which can make revenue per household as 6.6 ten thousand baht/year (at $\lambda \geq 0.7$) but that must be traded off with increase of highest amount of CO_2 emission (CObj5) compared with other objectives. Objective 3 (Prob3) yields the least household revenue, with weight value as 0.14 (3rd rank) together with amount of CO_2 being reduced than 50% (CObj4) resulting in the reducing of using areas for growing according to objective 3 till this affects overall net revenue.

Focusing on equity or balance in achieving goal of each objective: Results from the model are to make balance of the sum of 6 alternatives. The highest balance of the result would occur when value of $\lambda = 0.05$ which is the point that net revenue per household of alternative of objective1 (POb1) has value at 158.6 thousand baht/year (Figure 2 Pob1) which is lower than average agricultural household revenue (inc). Moreover, CO_2 amount tends to be increasing (objective 5 and 6) resulted from the result of objective 2 (POb2) and 3 (POb3).

Trade-offs analysis: Trade-offs occur during $\lambda = 0.05 - 0.65$ which are trade-offs between alternatives from net revenue objective 1 (Pob1) and emission of amount of CO_2 from Objective 5 (CObj5) and 6 (CObj6). The trade-offs have average value of -49.26 meaning that attempt to increase revenue from off-season glutinous and maize for 1 baht affects not only increase in green house gas, but also decrease in revenue of potato averagely 49 baht.

4.3 Resource usage as estimation from model

The result of the study reveals that overall use of the areas reaches the highest value during year 2 in February – April, especially when setting the creation of highest equity ($\lambda = 0.05$). Most of use are of potato, maize for animal feed and in-season glutinous rice growing, totaling 1,600 Rais. When focusing on highest efficiency ($\lambda = 1$), the land use is reduced to 897 Rais since most of the land is allocated to potato and in-season glutinous rice (objective 1) to achieve goal of highest net revenue and lowest CO_2 amount. In terms of water need, February and August of every year are the period that need the highest amount of water as high as 419 thousand cubic meters. This is because in that time, there have been growing activities of both in and off-season glutinous rice (objective 3). Glutinous rice needs much more water compared to other crops. As for hired labor needed, this would be in high demand during February and August of every year because it is the period of growing activities for in and off-season glutinous rice. Moreover, in February, labor is much needed for taking of potato product than other periods.

5. Conclusion and Discussion

This research employs MCDM method which consists of FAHP and MpMGP together with EGP. Calculation from FAHP shows that agriculturists give importance to revenue from growing in-season glutinous rice alternating with potato the most. This is followed by in-season glutinous rice alternating with maize, and lastly, in-season glutinous rice alternating with off-season glutinous rice. CO_2 that came from growing process receives low attention from agriculturists. As for achieving goal of increasing revenue together with reducing green house gas emission, this can be done by using philosophy of efficiency together with equity, that is 1) When focusing efficiency of revenue from in-season glutinous rice and potato, average revenue per household can increase up to the highest as 2 hundred thousand baht per year while CO_2 amount would be lowest when compared to other alternatives; 2) Attempt to increase equity or balance of sum of every objective equation would result in more emission of CO_2 because resource allocation would be allocated to alternatives that have ratio of CO_2 emission in high level such as that of in and off-season glutinous rice; 3) Increasing of revenue from alternatives that yield lower revenue would result in trade-offs or opportunity cost (Beck et al., 2008) from alternatives that yield higher revenue. So, attempt to grow in-season glutinous rice and maize for animal feed not only results in increasing green house gas amount emission, but also decreasing of revenue. Nevertheless, maize for animal fed can create income stability when drought occurs.

Bringing MCDM approach and the results from the study to apply in reality is necessary since it can make allocation according to pareto optimality with consideration to major criteria in economy, society, environment and community participation(Biswas and Pal, 2005). This is according to and can support government policy of collaborative farming that focuses on economical issue from economy of scale. Agriculturists would group themselves to form power in helping management in production, marketing and technology. Moreover, other benefit from this study is that it can help estimate effects and risks from crop growing so that it can help planning for crop growing and government policy making under the concept of green economy and help community economy to be sustainable.

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