Hue University Journal of Science
ISSN 2588–1205
Vol. 128, No. 5C, 2019, pp. 155–168; DOI: 10.26459/hueuni-jed.v128i5C.5132

APPLYING ANALYTIC HIERARCHY PROCESS (AHP) TO SELECT CLIMATE CHANGE ADAPTATION METHODS IN AGRICULTURAL SECTOR: A LITERATURE REVIEW

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Abstract: According to Conference of the Parties 22 (COP22) statement, climate change adaptation is the concern of not only an individual but also the whole society. Since the climate change issue is a multidimensional problem, decision-making in climate change adaptation is a complex process. In this paper, we analyze the advantages and disadvantages of three main group of decision-support tools, namely Expert preference, Monetary valuation, and Multi-criteria analysis (MCA). The paper recommends MCA in general and AHP in particular as effective tools to compensate for the disadvantages of other techniques as well as to overcome the challenges and requirements from the climate change adaptation decision-making process.

Keywords: climate change, AHP, MCA, monetary valuation, expert preference

1 Introduction

The twenty-first session of the Conference of the Parties (COP22) that took place from 07 to 18 November 2016, in Marrakesh, Morocco has confirmed again the agreement from nearly 200 countries on the climate change (CC) issues in COP21. This agreement proved that climate change is still not a "heated topic of debate" [23] but now became a real risk for whole humanity. According to the Intergovernmental Panel on Climate Change (IPCC), climate change refers to 'any change in climate over time, whether due to natural variability or as a result of human activity' [12, p. 871]. Climate change will lead to major impacts in the following sectors: water resources, agriculture, forestry, fishery, energy, transportation, and health [11] in which agriculture should be a focus due to its direct exposure to and dependence on the weather and other natural conditions. The Fourth Assessment Report of IPCC [12,p.282] concluded that climate change and variability will impact "*food, fiber, and forests around the world due to the effects on plant growth and yield of elevated CO_2, higher temperatures, altered precipitation, transpiration regimes, and increased frequency of extreme events, as well as modified weed, pest and pathogen pressure*".

The Fifth Assessment Report of IPCC confirmed that developing countries are expected to suffer the most from the negative impacts of climate change and variability. Especially, developing countries became more vulnerable due to their high dependence on the agriculture

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Submitted: February 27, 2019; Revised: March 24, 2019; Accepted: March 25, 2019

economy associated with the majority of the population living in rural areas where agriculture is the main income of livelihoods. It is predicted that for parts of Asia, crop yield is expected to decline up to 10% in the 2020s and 30% in 2050s compared with 1990s [12]. Obviously, adapting to climate change is an urgent action in the agricultural sector. However, adaptation is a multipurpose action that involves decreasing risk and vulnerability, looking for opportunities, enhancing the capacity of nations, regions, cities or private sector, communities, individual and natural system to deal with the impacts of climate change as well as mobilizing that capacity by implementing decisions and actions [30]. Indeed, identifying adaptation need is the most important in the climate change adaptation process and can help reduce risk and build capacity. IPCC [12] pointed out five kinds of needs in the climate change adaptation process such as biophysical and environmental needs, social needs, institutional needs, need for engagement of private sector and information, capacity and resource needs.

After identifying the adaptation needs, the next step of the climate change adaptation process is selecting adaptation options. There are many different methods to categorize adaptation options such as by different sectors and stakeholders, by national, sectoral or local adaptation plans, by structural, institutional and social options [5]. However, adaptation options are not always available to satisfy all adaptation needs due to the constraints and limitations during the adaptation process. Moreover, selecting adaptation options can be influenced by objective factors such as rate, the uncertain and cumulative effect of climate change [13]. Policy and market conditions may be "*a stronger driver of behavior*" than climate itself [3]. Hence, selecting an adaptation option rarely focuses on climate risks or opportunities alone. This selection should take into account other goals such as social benefit, poverty reductions or sustainable development. Decision making of adaptation options requires the mobilization of knowledge, experiences of researchers, local authorities as well as local people. Adaptation to climate change requires decisions and action that are taken by not only an individual but also from the whole society. Making a decision of climate change adaptation is a complex process and requires the combination of multiple sectors. Hence, it is a significant challenge of choosing one adaptation option that satisfies both effectiveness at rising resilience and social demands.

Consequently, selecting adaptation options is a multi-attribute decision making that requires an effective decision support tool. In this paper, by considering three different tools, we recommend AHP – one method belonging to Multi-criteria analysis (MCA) – as an effective way in choosing climate change adaptation. MCA provides a systematic way for decision-makers to make sense of a wide range of information that may be relevant to making adaptation choices. MCA enables decision-makers to create a structured framework for comparing a set of defined options across a number of diverse criteria so that they may evaluate adaptation options across a range of priorities or values [2]. MCA is highly relevant for adaptation and

suitable for the case of comparing multi options for a single problem [2, 33]. Especially, the criteria in the MCA method can consist of the uncertainty and intangible elements of a good adaptation [33]. Until now, MCA is widely applied as decision support for climate change adaptation [2, 10, 21, 31, 33]. MCA has benn considered as the most proper method of climate change adaptation since climate change is a multidimensional problem and the adaptive methods affect many aspects of human life such as the economy, society or ecology. There are several ways to weight and prioritize the criteria and options such as Multi-Attribute Utility Theory (MAUT), Analytical Hierarchy Process (AHP), and Outranking Methods. In our study, we choose the AHP method to conduct the MCA analysis. AHP is considered as an effective tool that can be used in the decision-making process of climate change adaptation. AHP allows consideration of both quantitative and qualitative data in the ranking of alternative options.

2 Overview of decision support tools

2.1 Expert preferences technique

Delphi method: This method is based on structural surveys and makes use of the intuitive available information of the participants, who are mainly experts [6].

SWOT method: This method can help decision-makers identify and understand key issues affecting their business, but it does not necessarily offer solutions. In addition, SWOT has some limitations as follows:

– SWOT analysis process can just focus on only one stage of the business planning process. For complex issues, it is necessary to conduct more in-depth research and analysis to make decisions.

– SWOT analysis only covers issues that can definitely be considered as strength, weakness, opportunity or threat. Hence, it is difficult to address uncertain or two-sided factors, such as factors that could be either a strength or a weakness or both, with the SWOT analysis.

Extrapolation method: This method may be understood as the extension of the data or process assuming that a similar process would be applicable beyond the given data. Extrapolation is an important concept used not only in mathematics but also in various other areas, such as sociology, psychology, and human experience. Extrapolation is said to be an opinion or an estimate about something extracted from known facts which extend or expand the given data into an area that is not known to arrive at conjectural knowledge of an unknown area.

2.2 Monetary valuation technique

There are some decision-support techniques that use the monetary term to evaluate the impacts of options including:

Financial analysis: An assessment of the impact of an option on the decision-making of organization's own financial costs and revenues.

Cost-effectiveness analysis: An assessment of the costs of alternative options which all achieve the same objective. The costs do not need to be restricted to purely financial ones.

Cost-benefit analysis: An assessment of all the costs and benefits of alternative options.

2.3 Multi-criteria analysis (MCA)

MCA is an approach that allows consideration of both quantitative and qualitative data in the ranking of alternative options [33]. The approach provides a systematic method for assessing and scoring options against a range of decision criteria, some of which are expressed in physical or monetary units, and some of which are qualitative. The various criteria can then be weighted to provide an overall ranking of options. These steps are undertaken using stakeholder consultation and/or expert input.

The approach identifies "*alternative options, selects criteria and scores options against these, then assigns weights to each criterion to provide a weighted sum that is used to rank options*" [31,p4]. The process allows the weights (for each criterion) to reflect the preferences of the decision-makers and the weighted sum of the different criteria is used to rank the options. MCA has been widely applied to ranking various alternatives, especially in the environmental domain. It is often included in guidance as one of a number of potential tools for option appraisal. It can be used for a strategy-level analysis or for individual projects or investment decisions.

3. AHP method and their application in selecting climate change adaptation methods

3.1 AHP steps

Step 1: Identification criteria and sub-criteria

This is actually the step of building a hierarchical tree by identifying the main goal (problem), the criteria, sub-criteria, and all alternatives. When creating a hierarchical tree, we should consider the following issues [25]:

– Introduce the problem as in detail as possible but not so thoroughly as to lose sensitivity to change in elements.

– Consider the environment around the problem.

– Indicate the element or attribute that is involved in the solutions.

– Identify the participants connected to the problem.

– The hierarchical tree has a descending structure from overall goal to criteria, sub-criteria, and alternatives. Hierarchy is not a traditional decision tree for some reasons: each level of the tree may present the different layer of a problem such as social, political and these levels can be evaluated with each other [25]. Normally, the global character will be presented at a higher level of the tree and the specific ones will be introduced at the lower level.

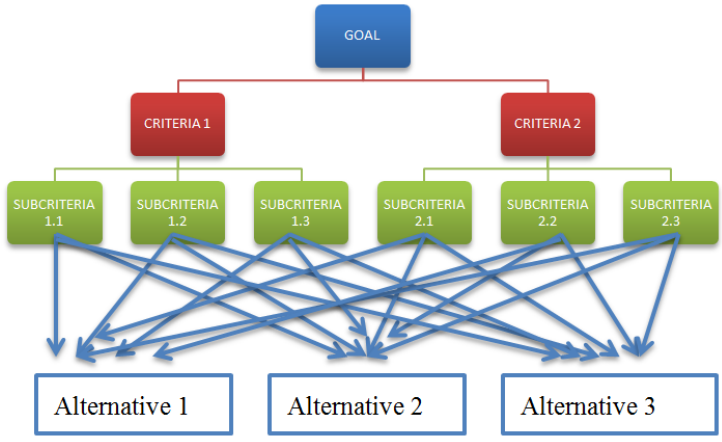

Figure 1. Hierarchical tree

Source: Author's synthesis

Step 2: Pairwise comparison

AHP technique uses the pairwise comparison to derive relative scales by taking judgment or data from a standard scale (table 2). The judgments are the results of pairwise comparisons. One of the advantages of pairwise comparison is allowing to focus judgment separately on each of several criteria or elements and do not concern others [24].

Scales of measurement

Scale (1: equal importance, 9: extreme importance) to evaluate the importance of criteria through pairwise comparison [26] is introduced in table 1

Table 1. Fundamental scale of absolute numbers

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor on activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is the highest possible order of affirmation

Source: How to make a decision: The Analytic Hierarchy Process [24]

Table 2. Pairwise comparison matrix of three criteria

Criteria	Criteria 1	Criteria 2	Criteria 3	Eigenvector	Weight
Criteria 1	W_{11}	W_{12}	W_{13}	$\|W1\|$	β_1
Criteria 2	$\frac{1}{W_{12}}$	W_{22}	W_{23}	$\|W2\|$	β_2
Criteria 3	$\frac{1}{W_{13}}$	$\frac{1}{W_{23}}$	W_{33}	$\|W3\|$	β_3
Total	$\sum W_{123}^1$	$\sum W_{123}^2$	$\sum W_{123}^3$	1	1

Source: [17]

where

$\sum W_{123}^1 = W_{11} + \frac{1}{W_{12}} + \frac{1}{W_{13}}$; $|W1| = W_{11}/W_{123}^1 + W_{12}/W_{123}^2 + W_{13}/W_{123}^3$; $|W2| = W_{123}^1/W_{12} + W_{22}/W_{123}^2 + W_{23}/W_{123}^3$; $|W3| = W_{123}^1/W_{13} + W_{123}^2/W_{23} + W_{33}/W_{123}^3$; $\beta_1 = \frac{1}{3}|W1|$; $\beta_2 = \frac{1}{3}|W2|$; $\beta_3 = \frac{1}{3}|W3|$

Step 3: Aggregation of the priorities

Aggregation of the priorities to have a ranking of the alternatives is carried out. This is done by determining the ratings of the alternatives with respect to each criterion and then adding up these ratings for all criteria. Calculating with the similar way with sub-criteria of each criterion, we have the weight of each sub-criteria (γ_i) as in the following table 3.

Table 3. Weight of each sub-criterion

Criteria	Sub-criteria	Priorities
Criteria 1 ($\boldsymbol{\beta_1}$)	Sub-criteria 11 (γ_1)	δ_1
	Sub-criteria 12 (γ_2)	δ_2
	Sub-criteria 13 (γ_3)	δ_3
Criteria 2 ($\boldsymbol{\beta_2}$)	Sub-criteria 21 (γ_4)	δ_4
	Sub-criteria 22 (γ_5)	δ_5
	Sub-criteria 23 (γ_6)	δ_6
Criteria 3 ($\boldsymbol{\beta_3}$)	Sub-criteria 31 (γ_7)	δ_7
	Sub-criteria 32 (γ_8)	δ_8
	Sub-criteria 33 (γ_9)	δ_9

Source: [17]

where

$$\text{Priorities } (\delta_i) = \beta_i \times \gamma_i$$

Identify the rating point of each sub criteria by the following formula

$$P_{ni} = a_{ni} \times \delta_{ni}$$

where P_{ni} is the rating point of alternative n for the sub-criteria i; a_{ni} is the assessing point of sub-criteria i of alternative n (based on Likert scale); δ_{ni} is the priorities of sub criteria i.

$$P_n = \sum_{i=1}^{n} P_{ni}$$

where P_n is the total point of alternative n; P_{ni} is the rating point of alternative n for the sub-criteria i.

Step 4: Control of consistency

Control of consistency is done by determining the consistency index, CI that is calculated as follows:

$$\mathbf{CI} = \frac{\boldsymbol{\lambda_{max} - n}}{\boldsymbol{n-1}}$$

where λ_{max} is the eigenvalue of the matrix; n is the size of the matrix.

A consistency index of up to 10% is tolerable [25]. A slight deviation of the consistency index from 10% is not a problem. A large deviation means that the judgments are not optimal and have to be improved.

3.2. AHP as an effective tool in the multi-dimensional decision-making process

Table 4. Comparison of tools in decision-making

Method	Advantages	Disadvantages
Expert preferences technique	– Large amount of quantity of information will be collected – Limited the constraints of group working (for Delphi Method) – Internal and external factors that are favorable and unfavorable to the objective's achievement. – Valuable information about objective's chances can be gained by viewing each of the four elements of the SWOT analysis independently or in combination[1] – Quantitative and qualitative information from a number of sources is combined. – Time and cost saving	– No mechanism to rank the significance of one factor versus another within any list. As a result, any factor's true impact on the objective cannot be determined. – Significantly impact company performance, business decisions must be based on reliable, relevant and comparable data. – The predicted objectives should be relatively stable.
Monetary valuation technique	– Assessing the alternatives under monetary valuation – Can include non-cash opportunity costs and shadow prices for some marketed inputs – Can take into account the willingness to pay or to accept for the public services – Losses and gains of all member of the society can be outlined based on CBA	– The relevant data related to non-marketed impacts are not always available and might be too expensive to collect – Some impacts cannot be quantified under the monetary term. – Cannot take in to account the interactions among different impacts
AHP technique	– Combine quantitative and qualitative data, using monetary and non-monetary units, and can, therefore, consider a much wider set of criteria, even where quantification is challenging or limited. – Be relatively simple and transparent, and can be done at relatively low cost and time-saving. – Expert judgment can be used very efficiently. – It involves multi-stakeholders and can be based on local knowledge as well as an academic one	– Results need further interpretation and elaboration in more detailed studies. – Different experts may have different opinions and will provide different scores, i.e. there is a degree of subjectivity involved. – Stakeholders may lack knowledge and may miss important options. – It may be difficult to give consistent scores to the alternatives. – Analysis of uncertainty is often highly qualitative.

Source: Author's synthesis

[1] http://smallbusiness.chron.com/advantages-amp-disadvantages-swot-analysis-41398.html

3.3 Application of AHP in climate change adaptation in the agricultural sector

Regarding Expert preferences technique, the Delphi method has been applied in identifying the successful adaptation to climate change through an iterative process, expert respondents coalesced around a definition based on risk and vulnerability and agreed that a transparent and acceptable definition should reflect impacts on sustainability. According to the final definition, agreed by the Delphi panel, successful adaptation is any adjustment that reduces the risks associated with climate change, or vulnerability to climate change impacts, to a predetermined level, without compromising economic, social, and environmental sustainability [8]. However, all participants in Dora et al. (2009) [8] agreed that the checklist criteria should be weighted, most refused to attribute weights, for various reasons. Many participants considered that the relative importance of specific criteria depends on the particular case to which the criteria are applied.

SWOT method is applied to evaluate the perception of Rwandan government officials, NGOs, and extension specialists about smallholder agroforestry adoption as a strategy for smallholder farmers in Rwanda. Due to limitations in human judgment and differing viewpoints among group participants, absolute consistency is not expected. Hence after using SWOT, Pair-wise comparisons are conducted separately for all factors within a category and a priority value for each factor is computed using the eigenvalue method [28]

CBA is used to evaluating global climate policy by sketching and analyzing the welfare foundations of cost-benefit analysis and from this perspective analyses the role of cost-benefit analysis in the climate policy debate, particularly with reference to intergenerational effects [18]. However, this method raised the problem of discount future that can bias against future generation.

Based on the advantages of AHP that have been analyzed above, it seems that AHP can solve the problems of this above method. AHP has been applied in several fields such as education, marketing, environment or agriculture. In this paper, we just focus on reviewing the study related to agricultural and climate change adaptation field.

AHP is used in assessing Agri-environmental measures (ARM) of the Rural Development Program in Slovenia [19]. In this paper, authors have identified three main criteria to evaluate one ARM including Social acceptability, Environmental reliability, and Economic feasibility. For each criterion, authors have built the sub-criteria to evaluate 23 alternatives. Thanks to AHP's result, the paper concluded that organic fruit, vine, and horticultural production are seen as the most important AEM in the case of Slovenia.

AHP is successfully applied in assessing the sustainability of agricultural systems [20]. The principles, criteria, and indicators have been identified to evaluate the sustainability of

agricultural system in the context of Sustainability Assessment of Farming and the Environment (SAFE). SAFE starts from defining sustainability as maintaining or enhancing the environmental, economic and social functions of an agro-ecosystem as formulated in a set of principles and criteria. Environmental principles are derived by considering in a systematic way the quantity, quality, and fluxes of all natural resources. Social and economic principles rest on present-day societal values and concerns. The proposed analytical framework is not intended to find a common solution for sustainability in agriculture as a whole, but to serve as an assessment tool for the identification, the development, and policies.

Applying AHP in a different aspect of agriculture, this method is also used to evaluate soil erosion in terms of land-use structure changes in the case study of Zhifanggou Watershed in Ansai, Shaanxi Province, China [15]. In this paper, the authors have identified the degree of impact of different level of land use through pairwise comparison matrix. The outcome of the AHP process is the land-use Structure Characteristic Index (SI) that can reflect the resulting impact of human factors and serve as an indirect measure of soil erosion variation. However, according to authors, AHP has some limitations such as subjective judgment, the degree of uncertainty...

Regarding climate change adaptation, AHP has been conducted to evaluate the sea level rise adaptation options under approach involving stakeholders in the case of Goal Coast, Australia [22]. In this paper, the authors have built five criteria to assess adaptation options for reducing vulnerability to sea level rise including applicability, effectiveness, sustainability, flexibility, and cost. In addition, five alternatives have been identified, including planned retreat, improve building design, improve public awareness, built a protective structure and take no actions. Moreover, the paper also invests the stakeholders' opinions for adaptation alternative including politician, experts, and residents. AHP's results show that in the case of Australia, effectiveness and sustainability are the most important criteria for one adaptation option while cost is not a major problem. Applicability and flexibility of the adaptation alternatives are of medium importance.

In the case of Viet Nam, AHP is exerted to prioritize irrigation asset renewals in the case of La Khe irrigation scheme, Vietnam [29]. In this study, assets were of four different types, canals, structures, offtakes, and pumps. The next level comprises the three major factors that affect the performance of assets: hydraulic performance HP), condition 0) and importance I). The lowest level is the criteria associated with each factor for each particular type of asset. After calculating the importance of judgment, relative weightings of each asset type and asset scoring, authors prioritized the renewals by the location of the asset and of asset types.

In a study on selecting the climate change adaptation methods for the coastal region of Phu Vang district, Thua Thien Hue province, Sen has successfully applied AHP techniques in

finding the most suitable adaptive methods for the study [17]. In this research, firstly, the alternative options that have been successfully applied in other areas of Vietnam would be used as references. Secondly, the criteria that would be used to assess the adaptive options have been identified based on the characteristics of study are in terms of society, economy and ecology. The criteria of level one include the coherence, the effectiveness, the resistance, and the sustainability. In each criterion, there are many sub-criteria that would be not the same for the different study areas. Finally, AHP has been conducted to weight the criteria through group focus discussion and key informants' interviews. Author has classified the adaptive methods into three groups: agriculture, husbandry, and aquaculture. Results show that for the case study of Phu Vang district, the resistance ranks the lowest priority when farmers considering an adaptive option. In terms of the final point, agriculture has the highest points (4.475) and aquaculture has the lowest point (3.789). In the agriculture group, planting bitter loopah at the wrong season is highly recommended. In the aquaculture group, a solution of feeding eal got the lowest point. Thanks to AHP techniques, the research found the proper climate change adaptive methods that satisfy multi-attribute purposes and will be feasible to apply in practice in the case of Thua Thien Hue province.

4. Conclusion and direction for future studies

4.1 Conclusion

As the conclusion of COP22, climate change adaptation now is the concern of not only an individual but also the whole society. Since climate change issue is a multidimensional problem, it is needed a mobilization of knowledge, experiences of researchers, local authorities as well as local people in selecting an adaptation option. Moreover, decision making in climate change adaptation is a complex process of selecting from many alternatives based on various criteria. Hence, MCA, in general, and AHP, in particular, are considered as an effective tool to overcome the challenges of selecting one adaptation option [27]. We cannot deny the advantages of AHP such as its ability to quantify the qualitative criteria, its flexibility in applying and integrating with different techniques [32], its diversification in the source of data collection, its consideration in multi-sector and stakeholders when selecting one adaptation option [16]. Thank to these advantages, AHP techniques can compensate for the disadvantages of other techniques such as expert preferences or monetary valuation techniques. However, this method still consists of some limitations, namely highly requiring exact calculation, the objective opinions from experts might influence the research's results, researchers should have experience and skills in implementing AHP. Despite the limitations, AHP is still an outstanding method in helping the policy makers decide which adaptation method can help farmers cope with climate change.

4.2 Direction for future studies

The analytic hierarchy process (AHP) has a special advantage in the multi-indexes evaluation, and geographical information system (GIS) is superior in spatial analysis. A combination of AHP and GIS provides an effective means for studies of regional eco-environmental evaluation. Aiming at the regional features of eco-environment and main environmental problems of study area the synthetic evaluation index system will be set up including the natural environment, disaster, environmental pollution, and social economy factors [34]. Supported by GIS, taking the county as the evaluation unit, the regional eco-environmental information system database and evaluated the eco-environmental quality of study area will be established. This combination is already widely applied in disaster controlling but rarely used in climate change adaptation strategy building. In particular, in Vietnam, there is only one study [9] that combines AHP and GIS for land use suitability analysis. Hence, this combination is a future direction for researchers who want to conduct studies in climate change adaptation in Vietnam.

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