APPLICATION OF ANALYTIC HIERARCHY PROCESS (AHP) IN DEVELOPING ECO-SUSTAINABILITY CRITERIA FOR THE COFFEE FARMING ASSESSMENT: A CASE STUDY IN DAK HA DISTRICT, KON TUM PROVINCE

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ABSTRACT

Dak Ha is one of the nine districts in Kon Tum province, covering an area of more than 84 thousand hectares, and has the largest coffee area in Kon Tum province. The study aims to develop a set of Eco-Sustainability criteria for the coffee tree model in Kon Tum province. The study employed a combination of methods for data collection and analysis, including interviews with 575 farmers and 15 experts, analytic hierarchy process (AHP) method, land suitability assessment method, multi-criteria analysis (MCA), and synthetic assessment of DPSIR. The findings identified 15 factors affecting the Eco-Sustainability of coffee cultivation in specialized areas with 6 factors having the most influence in the order of cost, profit, capital efficiency, water quantity and quality, soil quantity and quality, and productivity. On that basis, the study proposed programs and solutions to apply Eco-Sustainability criteria to contribute to the development of sustainable coffee production for Kon Tum province.

Keywords: *sustainable ecology, criterion assessment, coffee farming, applicable solution, Kon Tum province.*

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1. INTRODUCTION

The Central Highlands is one of the key economic regions of the country with significant potential for economic development in agriculture and forestry. Kon Tum is a province in the Central Highlands, with a natural land area of 967,729.83 ha [1]. According to data from the Department of Natural Resources and Environment of Kon Tum province (2020), the agricultural land area accounts for 902,391.01 ha (93.25% of the total natural area); while the area for planting perennial crops is 154,362.74 ha (15.74% of the total area) and the area for growing coffee is 25,206 ha [2]. Following the implementation of the province's crop restructuring project, the area of coffee in 2003 increased from 12,833 ha in 2015 to 15,265 ha in 2020 and by the end of 2020 reached over 25,000 ha [3, 4]. However, the rapid expansion of coffee production, which ignores coffee quality, causes many problems in terms of economic efficiency and the ecological environment, threatening the sustainability of coffee production. Currently, there are no clear criteria in Vietnam in general, and in Kon Tum province in particular, to evaluate the Eco-Sustainability of the coffee farming model, resulting in a lack of clarity in reflecting on the current state and making recommendations for

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ensuring the long-term development of coffee trees in terms of economy, society, and the environment. Therefore, it is very important to evaluate the factors affecting Eco-Sustanability in coffee cultivation to build a set of Eco-Sustainability criteria applicable to coffee cultivation. Proposing programs and solutions that apply Eco-Sustanability criteria is required to contribute to the development of Kon Tum province's sustainable coffee production.

2. RESEARCH METHODS

2.1. Research subject

Research location: The study was conducted in Dak Ha district, Kon Tum province.

Research subject: coffee farming households in 11 communes, towns, Dak Ha district, Kon Tum province.

Research date: These estimates are based on data collected over a 10-year period of time (2010-2020).

2.2. Research methods

- Survey method: survey, interview coffee farming households with the number of 575 farmers and 15 experts, details of this method have been presented in the previous article of the author group [5].

- Analytical and evaluation method: to assess the suitability of land for coffee farming in the Dak Ha district [6].

- Synthetic assessment method of DPSIR (Driving Force - Pressure - State - Impact - Responses) [7]: includes the following framework system: Dynamics - Pressure - Status - Impact - Response. The model describes the relationship between motivation - D (increasing socio-economic demands in agricultural production areas), pressure - P (excessive development pressure, waste sources that pollute and degrade the environment), current status - S (environmental quality), impact - I (problems related to changes in the ecological environment affecting people and nature, economic and social), reaction - R (solutions to protect the ecological environment).

- The Multi - Criteria Analysis (MCA) method combines the expert method for determining the set of weights for the criteria with the expert method for quantifying the criteria.

The MCA method has eight steps. However, experts use only steps 1 - 4 and 7 to analyze the decision support criteria for uncomplicated decisions. Matrixes are used to perform multi-criteria analysis.

(+) Determine the decision content. What is the purpose of the MCA method, who is the decision maker, and who is involved in the process?

Establish a hierarchical structure of Eco-Sustainability factors in coffee farming with two levels: level 1 includes three criteria: economic, social, and ecological environment; level 2 includes fifteen component criteria: cost; profit; capital efficiency; productivity; area; financial support; cultivation practices; technical assistance; jobs; the suitability of capital capacity; quantity and quality of water; soil quality; residues of fertilizers and pesticides; reducing biodiversity; increased disease.

The opinions of 15 experts are gathered based on the criteria, and the comparison value of the pairs of factors at level 1 and level 2 is analyzed, the comparison matrix is established, and the weights of the factors at each level are established.

(+) Determine alternative options.

After determining the partial weights of factors of level 1 and level 2, determine the global weight of the criteria.

(+) Define goals and criteria that reflect the value associated with the outcome of each alternative.

Determining the degree of influence of good factors on Eco-Sustainability in coffee cultivation in specialized areas.

(+) Describe the expected performance of each alternative against the criteria. If combined with steps 5 and 6, describe the effect with a score.

From there, develop a remedial plan for the affected factors.

(+) Assign weights to each criterion to reflect their relative importance to the decision.

(+) Combine weights and scores for each alternative to obtain an overall value.

(+) Check the results.

Based on the criteria that were measured and analyzed hierarchically, a reality check was conducted with the results of survey questionnaires on the farming situation of the people, the land was assessed, and samples were taken to analyze the indicators of soil and water sample components.

Building a map of natural soil adaptation for coffee trees in Dak Ha district, Kon Tum province [6].

(+) Conduct a sensitivity analysis of the results to changes in weights.

Analytical Hierarchy Process (AHP) [8]: functional hierarchical analysis was used to solve the problem in this study. The AHP method measures consistency using the consistency ratio (CR); if the value of the consistency ratio is greater than 10%, the judgment is random and should be repeated.

3. RESEARCH RESULTS

3.1. The set of Eco-Sustainability criteria for the coffee farming model suitable to the natural, economic, and social conditions of Kon Tum province

3.1.1. Factors affecting Eco-Sustainability in coffee cultivation

The results of the survey of 575 farmers in the Dak Ha show that the current farming situation is affected by 3 main factors: socio-economic and ecological environment. According to the research results of Joe Walker (2011), these three criteria can also be used to measure and evaluate the sustainability of the farming area, thereby, providing information to decide on agricultural farming planning [9].

Research results on the current status of coffee cultivation, types of coffee farming models, and economic efficiency of the models have been presented in the previous study of the authors [5].

3.1.2. Set of criteria for assessing Eco-Sustainability for coffee farming models

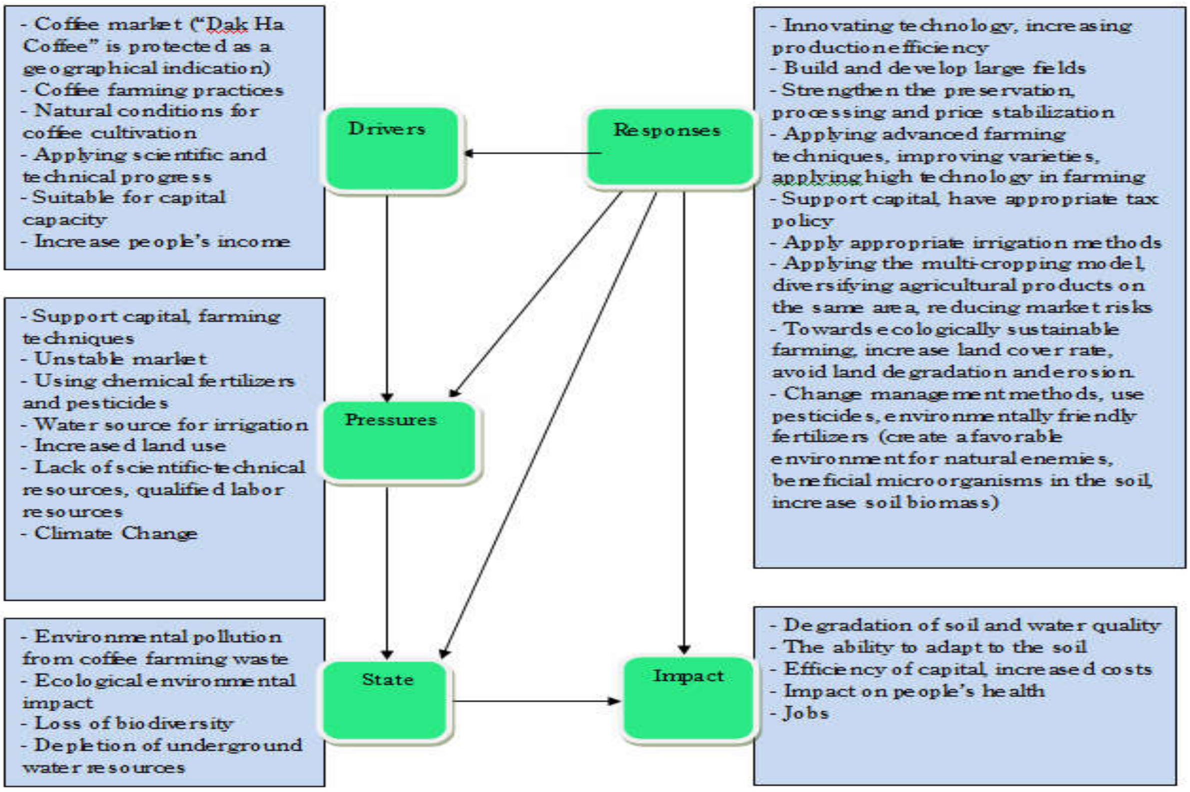

Figure 1. DPSIR diagram in coffee farming in Dak Ha district, Kon Tum province

Based on the DPSIR model analysis and the FAO's sustainable land use index framework, it was determined that 15 factors, divided into two functional levels, to analyze and assess the Eco-Sustanability of the coffee-growing area of Dak Ha, Kon Tum province, through the actual investigation of coffee cultivation in the specialized farming area of Dak Ha, Kon Tum province.

Building a comparison matrix with three factors at level 1 to synthesize factors: economic (KT), social (XH), and ecological environment (MST). Thereby, getting the expert opinion, and calculating the weight of the factors.

Table 1. The hierarchical structure of Eco-Sustainability factors in coffee farming

Level 1	Level 2	Sign	DPSIR	Sustainable land use
Economy (KT)	1. Cost	CP	I	Long term
	2. Profit	LN	I	Long term
	3. Capital efficiency	HQĐV	D	Production efficiency
	4. Productivity	NS	I	Long term
	5. Area	DT	I	Long term
Society (XH)	6. Financial support	HTC	D	Social acceptance
	7. Cultivation practices	TQCT	D	Social acceptance
	8. Technical assistance	HKT	P	Social acceptance
	9. Settlement of jobs	GQVL	I	Social acceptance
	10. The suitability of capital	KNV	P	Social acceptance
Eco-environment	11. Water quantity and quality	WATER	S	Safety
	12. Soil quality	SOIL	S	Safety

(MST)	13. Residues of fertilizers and pesticides	DL	S	Safety
	14. Reducing biodiversity	GDSH	S	Protection
	15. Increasing disease	GTDB	P	Protection

Table 2. Pairwise comparison of level 1 factors of experts

Comparision		Order of expert evaluation results									Aij
i	j	1	2	3	4	5	6	7	8	9	
KT	XH	3	2	4	3	5	6	8	7	8	37/8
	MST	3	2	5	2	3	7	6	5	3	911/250
XH	MST	1/2	1/2	1/2	1/2	1/3	1/2	1/2	1/2	1/5	54/125
CR(%)		4.6	4.6	8.2	0.8	3.3	7.1	1.6	1.2	3.8	3.9

From the results of consulting 15 experts, after synthesizing and analyzing, 9 opinions were selected to synthesize with the CR<10% consistency ratio, so the pairwise comparison matrix is consistent weight set.

Table 3. Comparison matrix and weighting factors of level 1

Criteria	KT	XH	MST	Weight (W)
KT	1	37/8	911/250	0.59
XH	8/37	1	54/125	0.11
MST	250/911	125/54	1	0.20

The results of the general comparison of experts in table 2, the weighting of the factors by the method of eigenvectors, and the determination of the weight vectors (Table 3) are as follows:

$[W_{KT}; W_{XH}; W_{MST}]$=[0.59; 0.11; 0.20]

Level 1 standards for the economy, society, and the natural environment are concretized into level 2 standards for evaluation.

Regarding the economic standard group: Create a matrix to compare five evaluation factors: Cost (CP); Profit (LN); Capital efficiency (HQDV); Productivity (NS); and Area (DT) from experts, select results with CR<10% consistency. The following results:

Table 4. Comparative value of level 2 factor pairs of experts in the economic group

Comparision		Order of expert evaluation results									Aij
i	j	1	2	3	4	5	6	7	8	9	
CP	LN	3	3	2	3	3	3	2	4	2	1353/500
	HQDV	3	4	5	4	3	5	4	5	3	783/200
	NS	4	3	3	3	3	4	5	8	3	151/40
	DT	2	3	5	4	5	5	5	5	4	203/50
LN	HQDV	2	3	4	3	2	4	3	2	3	1397/500
	NS	2	4	3	2	3	3	6	5	5	137/40
	DT	3	4	4	3	4	4	3	3	4	88/25
HQDV	NS	3	2	3	2	3	2	4	4	4	721/250
	DT	3	3	4	3	4	4	3	3	5	699/200
NS	DT	2	2	2	3	3	3	2	2	1	53/25
CR(%)		9.4	8.5	9.3	7.4	6.5	8.9	7.7	8.0	8.2	8.2

Table 5. Comparison matrix and weighting of level 2 factors in the economic group

Criteria	CP	LN	HQDV	NS	DT	Weight (W)
CP	1.00	2.71	3.92	3.78	4.06	0.43
LN	0.37	1.00	2.79	3.43	3.52	0.25
HQDV	0.26	0.36	1.00	2.88	3.50	0.16
NS	0.26	0.29	0.35	1.00	2.12	0.09
DT	0.25	0.28	0.29	0.47	1.00	0.06

Based on the results of the general comparison of experts in Table 4, the weights of the factors were calculated using the separate vector method, and the weight vectors were determined (Table 5) as follows:

[W_{CP}; W_{LN}; W_{HQDV}; W_{NS}; W_{DT}]=[0.43; 0.25; 0.16; 0.09; 0.06]

Regarding the social standard group: Similar to the economic standard group, the social standard group established a matrix comparing 5 evaluation factors: Financial support (HTC); cultivation practices (TQCT); technical support (HKT); Employment settlement (GQVL); matching capital capacity (KNV) from experts, choosing results with CR<10% consistency ratio. The following results:

Table 6. Compared value of level 2 factor pair of experts in the social group

Comparision		Order of expert evaluation results									Aij
i	j	1	2	3	4	5	6	7	8	9	
HTC	TQCT	3	5	3	2	2	3	5	3	5	13/4
	HTKT	2	4	4	4	5	3	3	3	3	3341/1000
	GQVL	5	7	3	3	4	4	4	4	3	991/250
	KNV	4	4	4	4	5	5	5	3	5	2139/500
TQCT	HTKT	1/3	1/3	1/3	2	1/2	1/2	1/3	1/2	1/3	233/500
	GQVL	3	3	2	3	3	5	3	3	2	1451/500
	KNV	2	2	3	3	3	3	2	4	5	358/125
HTKT	GQVL	3	2	2	2	4	3	3	4	2	2671/1000
	KNV	3	3	3	3	3	3	5	3	3	127/40
GQVL	KNV	2	2	3	2	2	2	2	2	2	523/250
CR(%)		5.1	8.8	9.0	3.8	8.7	7.3	6.7	8.0	9.0	7.4

Table 7. Comparison matrix and weighting of level 2 factors in the social group

Criteria	HTC	TQCT	HTKT	GQVL	KNV	Weight (W)
HTC	1.00	3.25	3.34	3.96	4.28	0.44
TQCT	0.31	1.00	0.47	2.90	2.86	0.17
HTKT	0.30	2.15	1.00	2.67	3.18	0.24
GQVL	0.25	0.34	0.37	1.00	2.09	0.09
KNV	0.23	0.35	0.31	0.48	1.00	0.07

From the results of the general comparison of experts in table 6, calculate the same as the level 2 factor belonging to the economic group, using the separate vector method to calculate the weights of the factors, thereby determining the weight vector (table 7) as follows:

[W_{HTC}; W_{TQCT}; W_{HTKT}; W_{GQVL}; W_{KNV}]=[0.44; 0.17; 0.24; 0.09; 0.07]

Regarding the group of ecological environment standards: a matrix comparing 5 evaluation factors is established: Quantity and quality of water (WATER); soil Quality (SOIL); residues of fertilizers and pesticides (DL); biodiversity Reduction (GDSH); incremental disease outbreaks (GTDB) from experts, choose results with CR<10% consistency. The following results:

Table 8. Comparative value of level 2 factors of experts in ecological environment group

Comparision		Order of expert evaluation results									Aij
i	j	1	2	3	4	5	6	7	8	9	
WATER	SOIL	1	2	2	1	1	2	2	5	1	1627/1000
	DL	5	3	3	3	7	5	3	3	5	977/250
	GDSH	3	4	4	7	5	7	5	7	7	5221/1000
	GTDB	5	3	4	7	5	7	7	7	7	1389/250
SOIL	DL	3	2	3	3	5	3	3	2	3	1451/500
	GDSH	5	3	3	5	7	5	3	5	5	2189/500
	GTDB	5	3	5	5	7	5	5	5	5	613/125
DL	GDSH	2	2	3	3	3	5	3	3	3	1451/500
	GTDB	2	3	3	5	5	5	3	3	5	3599/1000
GDSH	GTDB	1/3	1/3	1/2	1/2	1	1	1/3	1/2	1/2	51/100
CR(%)		7.6	7.0	5.4	4.9	8.9	6.4	6.7	6.0	6.7	6.6

From the Aij comparison results of 5 ecological environment factors shown in Table 8, a comparison matrix is established and weighted for these factors (Table 9).

Table 9. Comparison matrix and weighting of level 2 factors belonging to ecological environment group

Criteria	WATER	SOIL	DL	GDSH	GTDB	Weight (W)
WATER	1.00	1.63	3.91	5.22	5.56	0.43
SOIL	0.61	1.00	2.90	4.38	4.90	0.32
DL	0.26	0.34	1.00	2.90	3.60	0.16
GDSH	0.19	0.23	0.34	1.00	0.51	0.06
GTDB	0.18	0.20	0.28	1.96	1.00	0.08

Similar to the above, proceed to apply the separate vector method to calculate the weights of the factors, thereby, determining the weight vector as follows:

$[W_{WATER}; W_{SOIL}; W_{DL}; W_{GDSH}; W_{GTDB}]=[0.43; 0.32; 0.16; 0.06; 0.08]$

As a result, the partial weights of factor levels 1 and 2 have been determined. Continue to calculate the global weights based on these results:

Table 10. Hierarchical structure and weighting of Eco-Sustanability factors

Criterion level 1		Criterion level 2		Weight total
Criteria	W_1	Criteria	W_2	$W_i=W_1*W_2$
1. Economy (KT)	0,59	1. Cost (CP)	0.430	0.254
		2. Profit (LN)	0.250	0.148
		3. Capital efficiency (HQĐV)	0.160	0.094
		4. Productivity (NS)	0.090	0.053

		5. Area (DT)	0.060	0.035
2. Society (XH)	0,11	6. Financial support (HTC)	0.440	0.048
		7. Cultivation practices (TQCT)	0.170	0.019
		8. Technical assistance (HKT)	0.240	0.026
		9. Settlement of jobs (GQVL)	0.090	0.010
		10. The suitability of capital (KNV)	0.070	0.008
3. Eco-environment (MST)	0,20	11. Water quantity and quality (WATER)	0.430	0.086
		12. Soil quality (SOIL)	0.320	0.064
		13. Residues of fertilizers and pesticides (DL)	0.160	0.032
		14. Reducing biodiversity (GDSH)	0.060	0.012
		15. Increasing disease (GTDB)	0.080	0.016

3.2. Assessing the applicability of eco-sustainable criteria to the coffee farming model, the advantages and barriers of the application of the set of criteria

By applying the AHP method for factors at level 1 and level 2, it shows that:

For level 1 factors in Table 10, the economic pressure is the most influential factor on farming (W_{KT}=0.59) of the study area, followed by ecological environment factor (W_{MST}= 0.20) and social factors (W_{XH}=0.11) have the least influence on this process.

For 15 factors at level 2 and total weight shown in Figure 2, there are 6 selected factors that most affect the Eco-Sustanability of coffee production in the specialized farming area of Dak Ha, Kon Tum province, the order is as follows: Cost (CP) > Profit (LN) > Efficiency of capital (HQDV) > Water quantity and quality (WATER) > Soil quantity and quality (SOIL) > Productivity (NS).

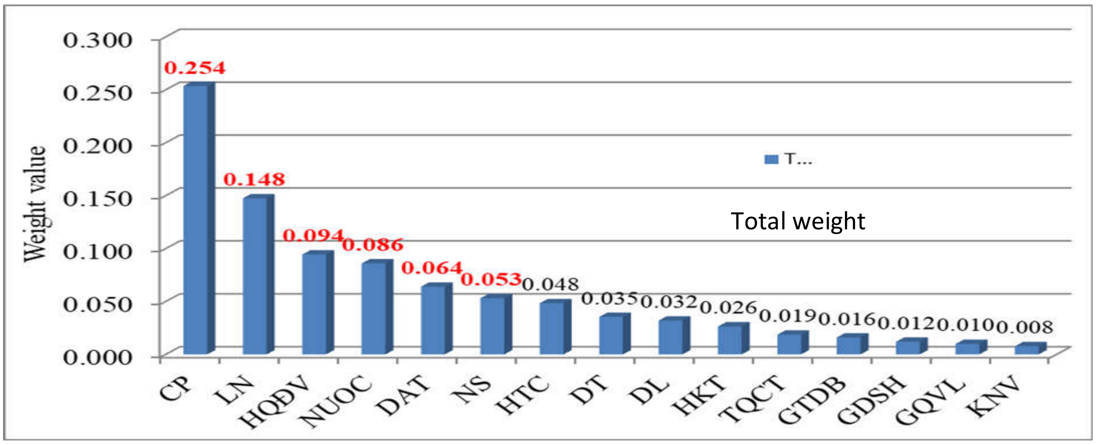

Figure 2. The influence degree of factors on Eco-Sustainability in coffee farming

a) Economic factors

Faced with the trend of increasing social integration and development, farmers are being greatly impacted by economic pressure, a reasonable farming model that is ecologically sustainable while also ensuring increased income. Improving living standards is a problem that people are always interested in and want to be answered in this period.

In Figure 2, the total weight of the influencing factors of economic criteria is as follows: Cost (W=0.254) > Profit (0.148) > Efficiency of capital (0.094) > Productivity (0.053) > Area (0.035). In which, 4 factors have the most influence on Eco-Sustainability.

In coffee farming, farmers cover the main costs of buying seeds, fertilizers, fuel for watering, pesticides, and labor. Although the conditions of capital that people pay for are different, the survey results show that, on average, the current total investment cost per hectare of coffee is about 62 million VND/ha. Table 11 shows that households paying for irrigation and pesticides per hectare of coffee ranges from 1 to 10 million VND; fertilizer costs are quite high, and more than 60% of households pay from 10 million or more for 1 ha of coffee.

Table 11. Service costs for coffee farming

Main cost	Cost/ha	Percentage of households (%)
Cost of organic fertilizer in business period	<3 million	1.29
	from 3 to less than 10 million VND	31.47
	from 10 million or more	67.24
Cost of chemical fertilizers in business period	<10 million	6.82
	from 10 to less than 20 million VND	26.71
	20 million or more	66.47
Irrigation cost	<4 million	8.04
	from 4 to less than 10 million VND	73.62
	from 10 million or more	18.34
Cost of pesticides	<1 million	1.81
	from 1 to less than 10 million VND	64.46
	from 10 million or more	33.73

According to the situation described above, the first factor that accounts for high costs in coffee farming is fertilizing coffee trees, particularly chemical fertilizers.

b) Regarding ecological environment factors

In the global index, the ecological factors are evaluated in order from highest to lowest, as follows: Water quantity and quality (W=0.086) > Soil quality (0.064) > Residue fertilizers and pesticides (0.032) > Increase in diseases (0.016) > Decrease in biodiversity (0.012). The quantity and quality of water and soil are the most pressing issues affecting the Eco-Sustainability (Figure 2) of the current farming model.

About water supply for irrigation [5] and the assessment of soil suitability for coffee trees in Dak Ha district, Kon Tum province [6] have been presented in the author's previous articles.

c) Regarding social factors

Social factors are one of the three factors that have the least influence on Eco-Sustainability in coffee farming; however, to ensure sustainable development, solving social problems is also a content that requires attention and support ensure long-term viability. The order of the global weight of each factor is as follows: Financial assistance (0.048) > Technical assistance (0.026) > Cultivation practices (0.019) > Job creation (0.010) > Suitability capital capacity (0.008).

As mentioned in the economic factor, coffee farming requires significant investment costs; therefore, people with limited capital require financial assistance to invest. Currently, households are looking for a variety of financial assistance for farming. To ensure output for products and investment funds, 42.2% of households collaborate with cooperatives, coffee purchasing companies, and material supply companies. Furthermore, 100% of households borrow from banks (55% from state banks, 11% from private banks, and 34% from other states, cooperative, and private support funds).

In the past time, with technical support for farming and harvesting coffee from the state, NGOs and coffee enterprises, 77.7% of households received technical training. The farmers who received training on planting, tending, harvesting, and preliminary processing techniques accounted for the highest percentage (76.3%), technical training on varieties (6.6%), grafting, and improvement (11.8%) and sustainable farming (14.6%) is limited.

4. CONCLUSION

The research identified 15 factors related to economic, social, and environmental issues based on the criteria for assessing the sustainability of agricultural organizations in general and coffee organizations in particular which is divided into 2 functional levels. Through testing and analysis, six factors have the greatest influence on the Eco-Sustainability of coffee production in specialized farming areas, with cost having the greatest influence (W_{CP}=0.254) and productivity having the least (W_{NS}=0.053). Other factors affecting eco-Sustainability in coffee cultivation are respectively profit (W_{LN}=0.148), capital efficiency (W_{HQDV}=0.094), water quantity and quality (W_{WATER} =0.086), and soil quantity and quality (W_{SOIL} =0.064).

REFERENCES

1. The Provincial Statistics Office in Kon Tum. (2020). *Statistical yearbook*. The Provincial Statistics Office in Kon Tum.

2. Department of Agriculture and Rural Development of Kon Tum province. (2017). *The situation of sustainable coffee development in Kon Tum province*. Department of Agriculture and Rural Development of Kon Tum province.

3. The Provincial Statistics Office in Kon Tum. (2012). *Results of total survey on rural, agricultural, and fishery in 2011 in Kon Tum province*. The Provincial Statistics Office in Kon Tum.

4. People's Committee of Kon Tum province. (2014). *Coffee development project in Kon Tum province until 2020, orientation to 2025*. People's Committee of Kon Tum province.

5. Le, H. V. *et al.* (2021). Assessment of the efficiency of Robusta coffee farming models in specialized areas in Dak ha district, Kon Tum province, *Journal of Agriculture and Rural Development,* 401, 150-157.

6. Le, H. V. *et al.* (2021). Assessment of land use and land adaptation for Coffea Robusta in Dak Da District, Kon Tum province, *Journal of Agriculture and Rural Development,* 413, 27-35.

7. Kristensen, P. (2003). *EEA core set of indicators*. European Environment Agency.

8. Saaty, T. L. (1980). *The analytic hierarchy process.* McGraw Hill.

9. Walker, J. (2011). Environmental indicators and sustainable agriculture. *CIAR Monograph Series*, 84, 323-332.