Sustainability evaluation of agricultural greenhouse structures in southern of Algeria using AHP, case of study: Biskra province

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Abstract: The protected cultivation of vegetables has considerably developed in southern of Algeria. However, the sustainability of this system has not been evaluated. The aim of this study is to find a greenhouse structure (Tunnel or Canarian) that promotes the agriculture sustainability in Biskra province using analytic hierarchy process (AHP). In that event, a survey was conducted in this region where nine criteria were selected according to the local conditions. The results obtained revealed that the farmer and the agricultural specialists shared the same vision regarding the weight of economic indicators with 74% and 66%, respectively. The AHP analysis provided that the Canarian greenhouse (CG) presented the ideal structure. This work might also help the decision makers and the researchers to implement a sustainable development policy.

Keywords: agricultural greenhouse, sustainability, AHP, Canarian greenhouse, Tunnel greenhouse

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1 Introduction

In the last two decades, Algeria has experienced a notable agricultural development driven by a prosperous market gardening in plastic greenhouses due to the favorable climatic conditions and the government's policy. As a result of this development, Biskra province became the first producer of early vegetables in the country (Allache et al., 2015) where, in the last 20 years, the area covered by greenhouse has multiplied five times (Belhadi et al., 2016).

This system of production has an economic, social and environmental impact, so that several studies have been conducted on greenhouse crop production in Biskra which were focused mostly on economic status and pest management (Daoudi and Colin, 2016; Rekibi, 2015; Allache et al., 2015), nevertheless, the sustainability of protected cultivation system has not been evaluated yet. At the beginning, farmers used the single tunnel greenhouse (TG) structure, then during the last ten years, the Canarian greenhouse (CG) structure has been expanded.

With these observations in mind, this study addresses the finding of a greenhouse structure (Tunnel or Canarian) that promotes the agriculture sustainability under the local conditions of Biskra province using analytic hierarchy process (AHP).

2 Methodology

This section elaborates on the methods used in this study. The study area is presented, then a survey and the groups involved in this work are described, followed by the alternatives explanation and the AHP method presentation. The final section defines the criteria used to determine which alternative is suitable for the region.

2.1 Study area

According to Rekibi (2015), Biskra province produces 32% of national protected crops production which makes it the first producer of early vegetables in

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Algeria. Therefore, the region was chosen to carry out the study. Biskra is located in the southeastern Algeria, the gateway to the Sahara. The height above sea level is 112 m. The chief town of the province is located at 400 km from the capital, Algiers. It has a surface area of 21,671 km², divided into 12 administrative districts with 33 municipalities (Figure 1). Biskra has a hot desert climate, with very hot and dry summers and mild winters with annual rainfall averaging between 120 and 150 mm year^{-1}. The average annual temperature is 20.9 ℃.

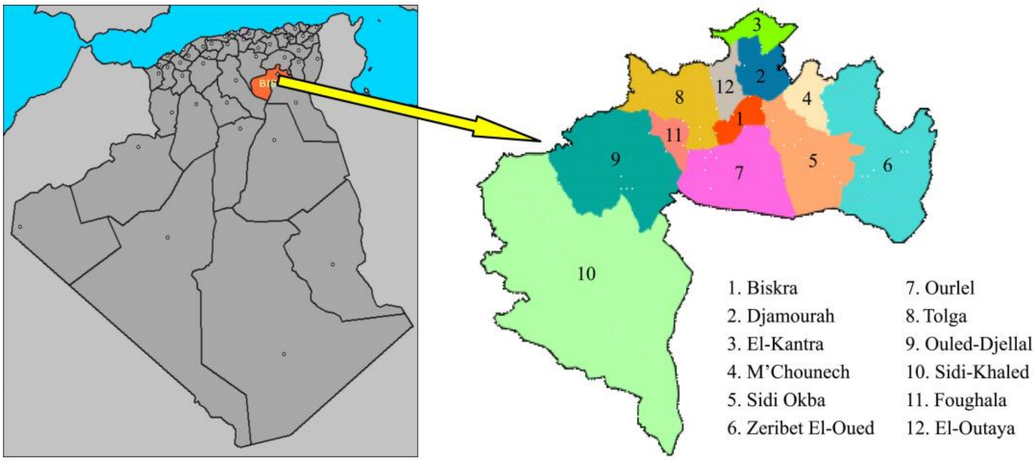

Figure 1 Situation of study area

2.2 Survey

The farmers are the most important actors who should have a strong opinion in selecting a suitable greenhouse structure for sustainable agriculture. Therefore, a survey was conducted during the season 2014-2015. The study employed face-to-face personal interviews using questionnaires providing information about the farm practices and the crop management. The data were collected from 63 farmers who were randomly selected from the six most productive municipalities, namely: M'ziraa, Ainnaga, SidiOkba, Elaghrous, Doucen and Lioua (Figure 1).

In parallel to this survey, interviews were developed with 10 agricultural specialists (policy makers, researchers and leaders of agricultural development plans) of more than 20 years of experience and from different local institutions (Biskra university, national institute of plant protection, scientific and technical research center on arid regions, direction of agricultural services, chamber of agriculture and technical-commercial agents).

2.3 AHP presentation

The AHP is a multi-criteria analysis method invented by the mathematician Thomas Saaty during the seventies (Saaty et al., 2006). It is intended to help the decision maker to refine its decision-making process by examining the coherence and logic of preferences. This is a method that can be used in the quantification of qualitative criteria, through its weighting. It has already been applied successfully in various fields (Ramos et al., 2014; Pugnet et al., 2013; Vijayakumar et al., 2010; Tacnet, 2009; Le Gallic et al., 2006). This method is able to identify and consider the inconsistencies of decision makers.

2.3.1 Fundamentals of AHP

The AHP is a rigorous methodology that is divided into series of important steps, namely: structure of the hierarchy, prioritization and checking the logical consistency of the analysis (Saaty, 2008).

2.3.2 Establishment of the hierarchical structure

This is an important step in problem analysis, thus providing more details to the hierarchy are very important to have good analytical skills and thinking. If the analysis gives unsatisfactory results or if the matrix is revealed inconsistent, the method allows us to change the inputs, or add other criteria.

The structure of the hierarchy is to define a hierarchical tree of three levels where the goal is at the top level, the selection criteria at the intermediate level and the alternatives in the lower level. Levels of a hierarchy are interconnected (Saaty, 2008).

2.3.3 Pairwise comparison

This step is mainly based on pairwise comparison of the different elements of the hierarchy by combining logical thinking and experience. The matrix presents the most effective framework for such comparisons. This matrix is used to evaluate the relative importance of an element (A_n) related to each other using an appropriate scale. Table 1 shows a weighting scale given by Saaty (2008).

Table 1 The 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 judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, verystrong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

Once the comparison matrix is completed, it is necessary to calculate the eigenvector (weight) of each elements of the hierarchy. Firstly, we must add the values of each column of the matrix. Then, divide all the inputs in each column by the total of this column to get a standardized matrix that allows meaningful comparisons between items. Finally, we calculate the average of lines by adding the values on each row of the normalized matrix and dividing these lines by the number of inputs they have. These operations lead to an overall eigenvector for the lowest level of the hierarchy.

Eigenvector indicates the order of priority or hierarchy of the different elements studied. This result is important for the evaluation of the probability, since it will be used to indicate the relative importance of each element operating.

2.3.4 Consistency of judgments

The AHP method offers the possibility to know how the judgments are consistent. Therefore, the first step in calculating the overall coherence is to take the original matrix, namely that of the input data, and multiply by the final relative priorities coming from the last step extracting eigenvectors. Then, it may calculate the total values for each line of the new matrix. Thirdly, the total values of each line will be divided by the value of the eigenvector associated with it. Fourthly, it suffices to calculate the average of the values obtained in the previous steps. The result of this calculation is represented by $\lambda_{\max}$. At this stage, the coherence index (CI) is defined by Equation (1).

$$CI = \frac{(\lambda_{\max} - n)}{(n-1)} \quad (1)$$

where, n is the number of comparing criteria.

The ratio of coherence (RC) is the ratio between CI and a random consistency index (CA) (Equation (2)).

$$RC = \frac{CI}{CA} \leq 0.1 \Rightarrow \text{we accept the matrix} \quad (2)$$

The CA index, presented in Table 2, results from a large number of replications. It is considered acceptable for a ratio with a consistency less than 0.10.

Table 2 Values of the random consistency index (CA) according to the order of the matrix

n	1	2	3	4	5	6	7	8	9	10	11
CA	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51

2.4 Alternatives

Biskra, consolidating its initial focus on date palms, now also specializes in greenhouse vegetable crops, during the last decade (Daoudi and Colin, 2016). According to Belhadi et al. (2016), the economic benefit generated by the protected cultivation are more important, to the farmer, (41.13%of total income) than the income generated by the date palm cultivation. These observations lead to conclude that the protected cultivation system is very important in this region and as a consequence this work is devoted to study its sustainability.

In the study area, existing greenhouses are mainly in single tunnels which are often grouped in larger numbers. Recently, the use of Canarian greenhouses has been spreading. Noting that, local farmers build the CG according to the Moroccan experience.

The focus in this paper will be on the judgment of a protected cultivation structure (Tunnel or Canarian) that would be economically viable, environmentally sound and socially responsible.

2.4.1 Alternative 1: Tunnel greenhouse (TG)

TG is the most common structure in the visited municipalities with a surface of 3549.84 ha (DSA, 2012). There is a succession of arches fixed into the soil and covered with a plastic film; it has a standard dimension, 8 m in width, 50 min length and 3 m in height. However, this structure presents some problems, such as: the difficulty in movement within, lack of good natural ventilation, proliferation of fungal diseases and low light transmission.

2.4.2 Alternative 2: Canarian greenhouse (CG)

It is located exclusively in three Eastern municipalities: (M'ziraa, Ainnaga and SidiOkba) with an area of 24.76 ha (DSA, 2012). This type is made of a metallic structure on which a rigid grid of wire is placed to attach the plastic film and the insect-proof screens. The surfaces are variable from 0.25 to 1 ha according to financial capacity of the owner. Mostly, this kind of greenhouse is equipped with a ventilation system and offers an easy passage for the machine.

2.5 Criteria Selection

The term "criteria or indicator" is often vague, heterogeneous and variable over time and space (Roy and Chan, 2012). Indicators are variable for different countries, regions, and development stages. Therefore, indicators used in one system are not necessarily applicable to other systems (Qiu et al., 2007; Rasul and Thapa, 2004).

This stage presents the most important step to create a preferment model. Selection of criteria consists in determination the indicators that could be used to measure the sustainability of greenhouse structure. The elaboration of these criteria should be with the principal actors involved in agricultural production system which are the farmers and the agricultural specialists. Based on the survey and an extensive literature review, the indicators were selected.

At the end of this stage nine criteria were chosen suitably with the local conditions including productivity, profitability, employment, chemical inputs, tillage, irrigation system, biodiversity, quality of life and health safety. These criteria could be classified into three main dimensions of sustainability, viz: economic, social and ecological which will be briefly described below.

2.5.1 Economic criteria:

Several economic indicators have been considered by many studies. An analysis indicated that an agricultural system is economical viable if it is profitable (Castoldiand Bechini, 2010; Bechiniand Castoldi, 2009; Meul et al., 2008; Rasul and Thapa, 2004) productive (Meul et al., 2008) and increases employment (Gomez-Limon and Riesgo, 2009).

A. Productivity (PRD). The yields of greenhouse were estimated per labor and capital invested. For the farmers PRD represent the most important criterion.

B. Profitability (PRF). PRF was represented by the Gross Margin (GM) which it is the difference between Gross Incomes (GI) and Variable Costs (VC). GI was calculated using the production quantities multiplied by local average selling price. VC (dollar ha^{-1}) included the purchase of seeds, pesticides, fertilizers, fuel consumption, transportation, irrigation network and occasional labor dedicated to the crop. This criterion contributes greatly to enhancing the financial and social status of farmers.

C. Employment (EMP). EMP indicated the number of seasonal and permanent worker involved during one season. Interviews with the farmers revealed that the labour market remained weak and instable which presented a major threat to the agricultural sustainability in Biskra.

2.5.2 Ecological criteria

A. Chemical inputs (CHI). As considered by Gomez-Limon and Riesgo (2009), Meul et al. (2008), Geng et al. (2014), and Reig-Martınez et al. (2011), this criterion was taken in our study. It was the amount of fertilizers and pesticides used during the season. Soil of Biskra region characterized as low fertility, thus fertilizers are increasingly used. As well, the local climate factors aid in pest and disease invasions, which induce large use of pesticides. Nevertheless, these chemical inputs have a harmful effect on the environment and human health thus the sustainability of the activity (Patra et al., 2016; FAO, 1998).

B. Tillage (TIL). Mainly, the farms visited has a fragile soil which means frequent passes of tractor causes a formation of plough-pan. Hence, the number of tractor passes was calculated for one season. The visited farm use a moldboard plow as first tool for ploughing, while in some cases they use disk harrows, rotary tiller and ridger. These practices participate certainly in soil degradation (Vian, 2009). Sydorovychand Wossink (2008) took account of the soil quality (physical, chemical, and biological condition).

C. Irrigation system (IRR). The overwhelming majority of farmers use drip irrigation. It is the most economic system in term of water consumption allowing conservation of water resources but the consumption of water is different from farmer to another (Geng et al., 2014; Gomez-Limon and Riesgo, 2009; Walter and Stützel, 2009).

D. Biodiversity (BID). Biodiversity indicator was investigated by many works such as Rasul and Thapa (2004); Gomez-Limon and Riesgo (2009); Sydorovych and Wossink (2008) and Pacini et al. (2003). It explains the presence of other crops’ cultivation in the farm besides the greenhouse cultivation. The farmers cultivate other crops in order to ensure supplement revenue.

2.5.3 Social criteria

A. Health safety (HES). This criterion shows the toxic effect of pesticide application on workers. It means to evaluate the toxicity which leads us to adopt the corresponding protection degree of labor as a scale of evaluation. Thus, six categories were recorded, namely:

1) No means of protection;

2) Mask;

3) Mask + gloves;

4) Mask + glasses;

5) Mask + gloves + glasses;

6) Complete protective safety clothing.

B. Life quality (LIQ).It is the overall well-being of farmers and their families. Two groups of farmers were classified, the small-holders which represented the majority, living in difficult conditions, and the great-holders with a good life level.

3 Results and discussion

3.1 Establishment of the hierarchical structure

As the first step in AHP method, a hierarchical structure model was established with the goal of determining the most sustainable alternatives (greenhouse farming Tunnel or Canarian) through nine criteria belonging to the environmental, social and economic pillars of agricultural sustainability. Figure 2shows different components of that hierarchy.

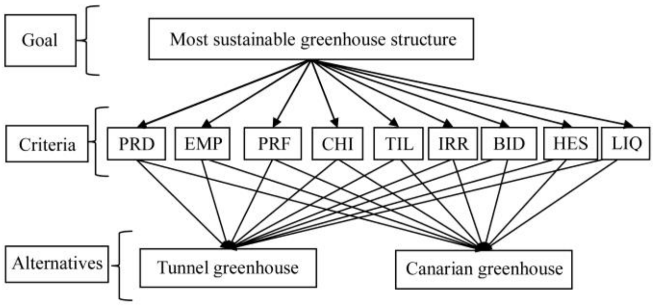

Figure 2 Hierarchical structure for the selection of sustainable greenhouse structure

3.2 Pairwise comparison

As a decision support system, *SuperDicision* software has been used to perform the AHP application. First of all, 36 questions came from the pairwise comparison of nine criteria in a way that each two criteria were treated as a question. Therefore, the participant indicated the relative importance of one element related to each other with respect to the overall goal based on an appropriate scale (Table 1). Then, to find the compromise answers among interviewees, geometric means were calculated for each question. Hence, the comparison matrix was input into decision support system to produce criterion weights at each level of the hierarchy. Lastly, the authors made the comparison, with compromise, between the alternatives (CG and TG structure) with respect to each criterion based on data collected during the survey.

3.2.1 Farmers

3.2.1.1 Weight matrix

After pairwise comparisons of all the elements of hierarchical structure, a weight matrix was constructed (Table 3).

This operation was done according to the experience and the farmers' point of view. During the survey, it was difficult to evaluate explicitly the importance of each element compared to others (pairwise comparison) from the farmers due to their low education level, thus, the answers were implicitly defined. Then, the normalization of criteria was carried out by calculation of the eigenvector for each one (Table 4).

Table 3 Matrix of pairwise comparison of criteria for farmers

	BID	CHI	EMP	HES	IRR	LIQ	PRD	PRF	TIL
BID	1	0.25	0.143	0.25	0.2	0.25	0.125	0.111	0.2
CHI	4	1	0.333	1	0.333	1	0.143	0.125	2
EMP	7	3	1	3	2	3	0.2	0.167	4
HES	4	1	0.333	1	0.5	1	0.167	0.143	0.5
IRR	5	3	0.5	2	1	2	0.143	0.125	1
LIQ	4	1	0.333	1	0.5	1	0.167	0.143	0.5
PRD	8	7	5	6	7	6	1	0,5	6
PRF	9	8	6	7	8	7	2	1	7
TIL	5	0.5	0.25	2	1	2	0.167	0.143	1

Table 4 Eigenvector of each criterion for farmers

Name	Weight
BID	0.01654
CHI	0.04482
EMP	0.10771
HES	0.03926
IRR	0.06480
LIQ	0.03926
PRD	0.27566
PRF	0.36013
TIL	0.05183

According to Table 4, the eigenvector for the most sustainable greenhouse structure comes in the following order: Profitability (36%), Productivity (28%), Employment (10%), Irrigation system (6%), Tillage (5%), Chemical inputs (5%), Health safety (4%), Life quality (4%), and Biodiversity (2%).

It seemed that the economic criteria (productivity, profitability and employment) presented the most important indicators for farmers, since the sum of their eigenvectors was more than 74%. As a result, the sustainability of protected cultivation in Biskra was much related to the economic efficiency. This result shows that the ecological and social impact of this agriculture activity is ignored by the farmers. Consequently, the most suitable greenhouse structure for them is the one that has economic advantages.

3.2.1.2 Comparisons of the sustainable greenhouse structure with respect to the criteria

We evaluated each greenhouse type with each criterion. The result shown in Table 5 gives the eigenvector (weight) of both greenhouse structures.

Table 5 Average score of each greenhouse structure for farmers

Name	Weight
Canarian greenhouse	0.722127
Tunnel greenhouse	0.277873

As shown in Table 5, the CG presented the most sustainable structure with a score of 72% in respect of the TG. These results could be explained by important yields recorded with CG as the first reason. Furthermore labor prefers working under CG structure for ease of pest management compared to the TG structure.

3.2.2 Agricultural specialists

3.2.2.1 Weight matrix

Every specialist has received 36direct questions that presented the pairwise comparison of nine criteria selected in a way that each two criteria were treated as question. Therefore, the geometric means were calculated to find the compromise answer for each question from the participants. Hence, the comparison matrix was input into decision support system to produce criterion weights at each level of the hierarchy.

The Table 6 and Table 7 illustrate the matrix of criteria pairwise comparison and the weight of each criterion, respectively, according to agricultural specialists.

From the Table 7, the eigenvector for the selected criteria were ordered as follow: Profitability (34%), Productivity (25%), Tillage (13%), Irrigation system (8%), Employment (7%), Life quality (6%), Biodiversity (3%), Health safety (2%) and Chemical inputs (2%).

Table 6 Matrix of criteria pairwise comparison for agricultural specialists

	BID	CHI	EMP	HES	IRR	LIQ	PRD	PRF	TIL
BID	1	2	0.25	2	0.5	0.3333	0.1667	0.1667	0.1667
CHI	0.5	1	0.1667	2	0.2	0.5	0.1429	0.125	0.1429
EMP	4	6	1	3	1	1	0.3333	0.25	0.25
HES	0.5	0.5	0.3333	1	0.1111	0.2	0.2	0.1667	0.125
IRR	2	5	1	9	1	2	0.1667	0.1429	1
LIQ	3	2	1	5	0.5	1	0.25	0.1667	0.25
PRD	6	7	3	5	6	4	1	0.3333	5
PRF	6	8	4	6	7	6	3	1	5
TIL	6	7	4	8	1	4	0.2	0.2	1

Table 7 Eigenvector of each criterion for agricultural specialists

Name	Weight
BID	0.0312
CHI	0.0230
EMP	0.0725
HES	0.0211
IRR	0.0845
LIQ	0.0557
PRD	0.2388
PRF	0.3389
TIL	0.1343

Compared to farmers, agricultural specialists have disapproved economic criteria (productivity, profitability and employment) with an aggregated score of more than 66%. The environmental indicators (tillage and irrigation system) presented some increase with a value of 21% regarding to the farmers. Consequently, the most suitable greenhouse structure for the agricultural specialists is that would be principally economically viable and lightly environmentally sound. The tendency of agricultural specialists is slightly different from farmers one. This statement could be explained by the shortage of studies in this field which demonstrate the impact of protected vegetable production on the environmental and social dimensions in Biskra, which will conduct the agricultural specialists to make choice suitable with the farmer’s point of views.

3.2.2.2 Comparisons of the sustainable greenhouse structure with respect to the criteria

As shown in Table 8, the CG presented the most sustainable structure with a score of 75% with regard to the TG. The result obtained was almost equal to that found with the farmers.

Table 8 Average score of each greenhouse structure for agricultural specialists

Name	Weight
Canarian greenhouse	0.749
Tunnel greenhouse	0.251

3.3 Consistency of judgments

A consistency index was calculated to verify the accuracy of the decision. Results showed that the index of consistency were 0.061 and 0.0993 for farmers and agricultural specialists respectively, which were less than the reference index (0.1), proving that the logics of judgment were consistent and acceptable.

3.4 Synthesizing findings

This step allows verifying the results of the AHP decision. The analysis of data collected from 63 farmers could approve that the CG was more sustainable structure than TG. For that, the behavior of each dimension of sustainability has been examined vis-à-vis each kind of greenhouse structure, as follows.

3.4.1 Economic dimension

In term of production, the survey revealed that the CG production is increased by 150% compared with the TG due to several factors. The number of clusters per plant in CG could be doubled compared to the TG. The fertigation was carried out using a complete head station in CG while in TG the farmers used ordinary containers. The pollination in CG was better controlled using pollinating bumble bees than in TG. These factors let farmers sustain their agricultural activity.

Concerning the employment, the collected data showed that in CG the technology used was more sophisticated regarding to the TG which attracted the labor.

Despite the CG was more expensive than TG, the income from CG still encouraged the farmer to use it.

3.4.2 Environmental dimension

The environmental dimension is very important for the next generations. It was concluded that the CG was environment friendly where the number of pesticides treatments was 26 times for CG and 35 times for TG and the average amount of fertilizer used per hectare was around 900 kg ha^{-1}with CG while it was around 3500 kg ha^{-1} with TG, thus it was three times more of TG than CG. For the biodiversity, it was found that all the farms with CG were cultivated by other crops, while in the case of TG, 60 % of farms were cultivated by other crops. The water irrigation consumption in TG was three times more than that in CG, which resulted in water resources depletion.

3.4.3 Social dimension

Several indicators help us to evaluate the farmer well-being; in our case we have based only on the daily incomes while the incomes from CG were five times more than TG. About healthy status, we have noted that the farmers used protection means in TG more than that in CG for reason that high treatment number increased the risks of intoxications.

4 Conclusions

The overall goal planned for this work was to determine the most sustainable greenhouse structure among the two existed type (Tunnel and Canarian) in the Biskra province. For this a survey was conducted in this region and nine criteria were chosen according to the local conditions. The results obtained revealed that the farmer and the agricultural specialists shared the same vision on the importance of economic indicators where the sum of their weights was around 74% and 66%, respectively. The AHP analysis provided that the ideal greenhouse structure was the Canarian type.

The selection of greenhouse structure is very important to sustain the protected vegetable production system in Biskra. Viewing the shortage studies on this subject, this work could provide an information support to the decision makers in order to plan the development policy and to the researchers for enhancing their knowledge on the sustainability in the study area.

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